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The Magazine of Space Exploration
March/April 1990

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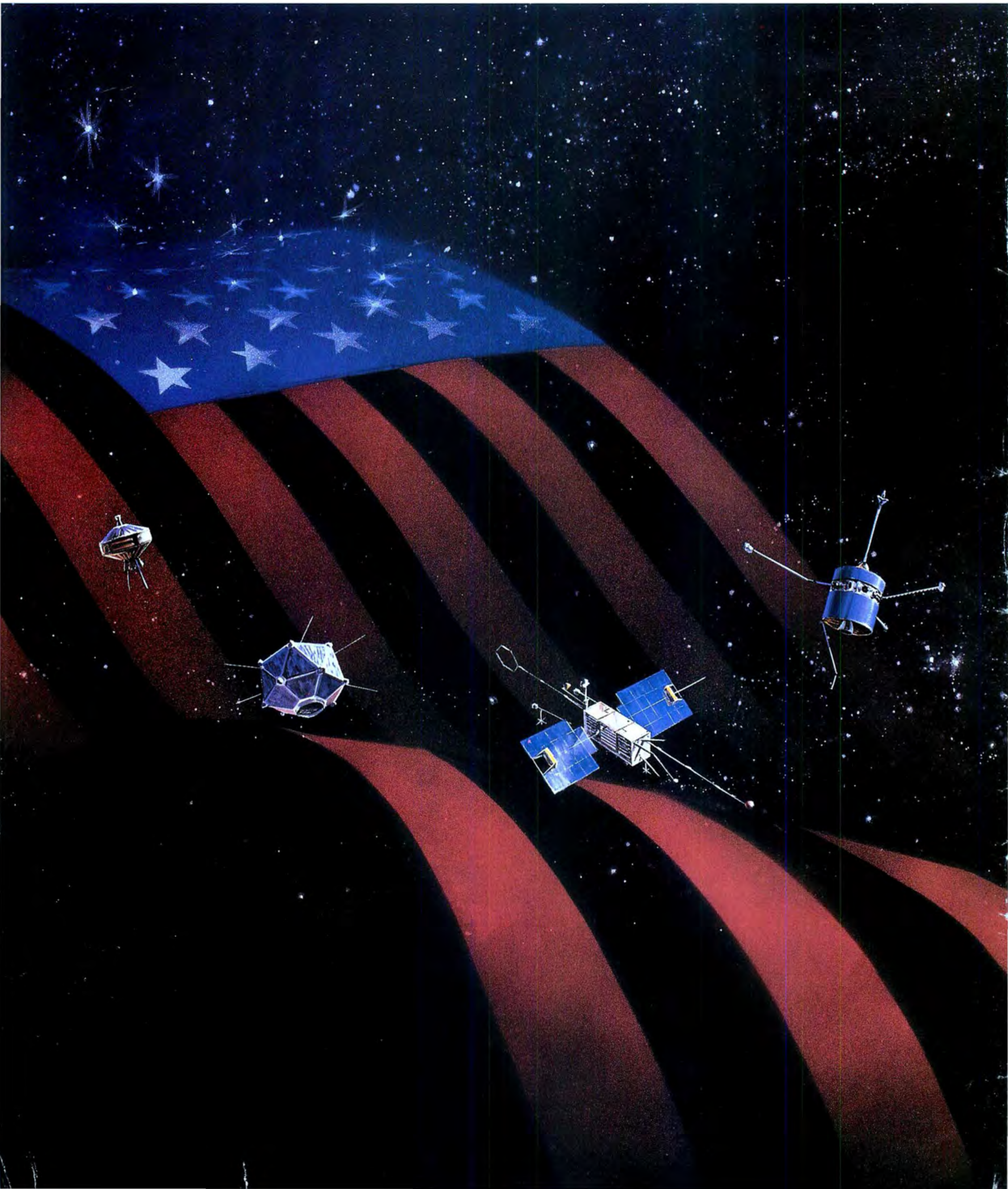

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March/April 1990

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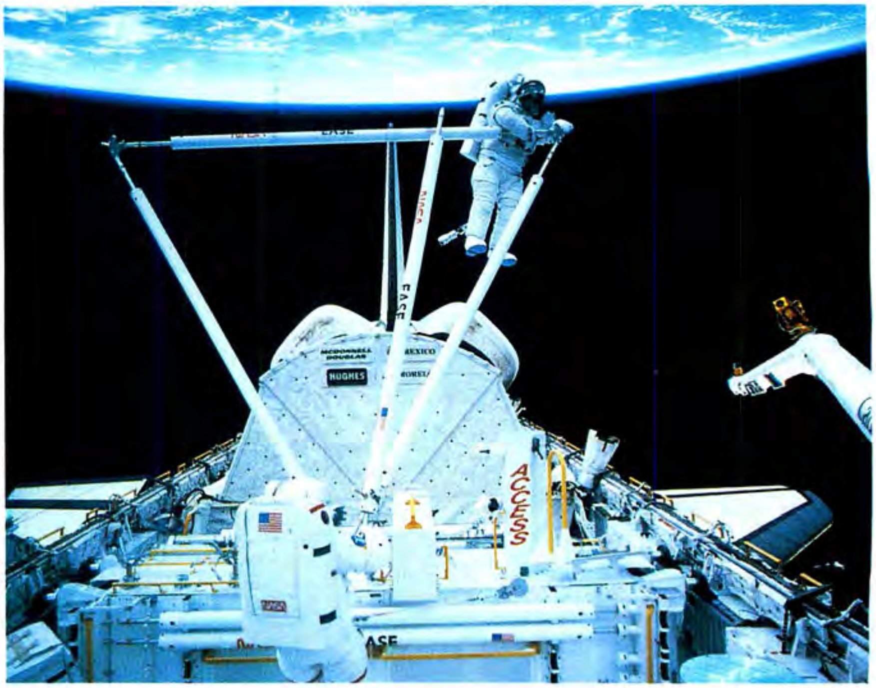

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Twenty years in the planning, the Hubble Space Telescope is about to show us the Universe as it really is, not as we see it through Earth's murky atmosphere. See the article beginning on page 24. (Cover photo: Space Telescope Science Institute/AURA; Inset art: Paul Hudson.)

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for another walk.

Letters

Impractical or Crucial?

Concerning the Space Studies Institute proposal for a privately funded and relatively cheap Lunar Prospector mission ("The Private Vector," November/December 1989): It is a great idea, but may well be impractical. The Planetary Society (in cooperation with the Space Studies Institute and other groups) conducted a study of this idea a couple of years ago and reluctantly concluded, as Maryniak himself noted, that the scientific value of anything that could be done cheaply was insignificant. If you cannot prove that water is not reasonably accessible in the Moon with the scientific experiment, then what is the value of the mission? When it is all over we would simply say, "We still don't know." Chances of lunar water being accessible are remote, and recent scientific studies have cast doubt on the original idea that water may be trapped in the permanently shaded areas on or near the surface at the lunar poles. The old Apollo gamma-ray instrument enabling what we termed a "cheap, quick mission" to be done has insufficient sensitivity for a meaningful experiment.

I hope some creative ideas can be found to make the Lunar Prospector idea useful. We searched and found none. Until then, I think we should resist the temptation to get excited about its claims. The United States, the Soviet Union and Japan are all studying lunar orbiters with sufficiently good instrumentation to provide first-class scientific results about the possibility of water on the Moon and other geochemical data. Those are the missions that will need our support. One hopes that an international effort for a rather modest government lunar orbiter can be garnered in the next several years so that this mission could be flown by 1995. It is an important precursor to understanding what sensible role the Moon might play in human exploration of the Solar System.

Louis Friedman
Executive Director, The Planetary Society

Gregg Maryniak of the Space Studies Institute responds:

Friedman's comments miss a number of critical points. First is the characterization of the mission as a single-purpose flight. In addition to the elemental and water mapping capabilities provided by the gamma-ray spectrometer (which will be enhanced to provide sensitivities within three to four times that of proposed future technologies), Lunar Prospector will fly a total of five experiments.

Although the mission is modest in scope compared with future proposed missions, it is inappropriate to equate modest scale with experiment performance. In fact, the principal investigators engaged in developing the Lunar Prospector payload are in many cases developing payloads for NASA lunar and Mars missions as well.

Friedman implies that Lunar Prospector might somehow interfere with eventual NASA Lunar Observer missions. The opposite appears to be true. Lunar Prospector can provide valuable data for a later mission—for example, its data on the Moon's gravity field can feed directly into mission planning to extend the life of the Lunar Observer.

The Moon is the stepping stone for the exploration and settlement of the Solar System. Getting resource and science information about our nearest neighbor is a crucial next step for space development. As such, we believe that two opportunities for exploration are better than one. The Space Studies Institute has always strongly supported the Lunar Observer, and NASA has announced its support for Lunar Prospector as well (the agency is making an Apollo gamma-ray spectrometer available for the mission).

We are pleased with NASA's support of the first private sector space probe and we hope that the agency's positive response will continue to be echoed in the community at large.

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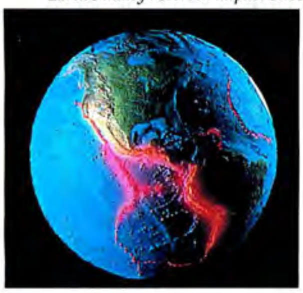
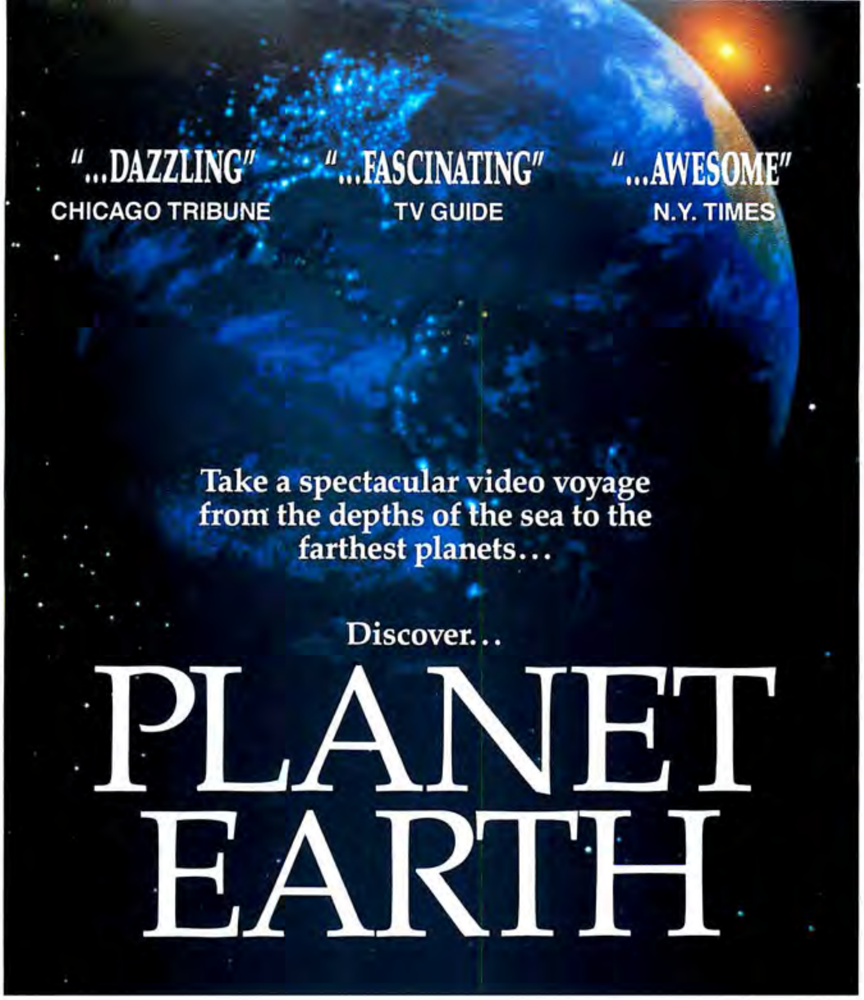
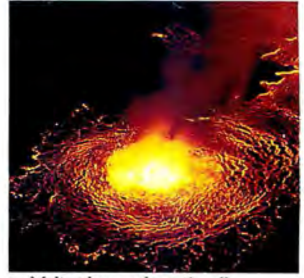
Test tube recreation of Earth's primeval chemistry.

Arizona's Meteor Crater: one of Earth's many asteroid impact sites.

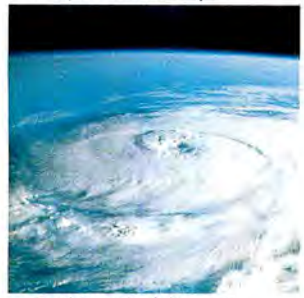


An ancient "supercontinent" tearing apart to form today's world.

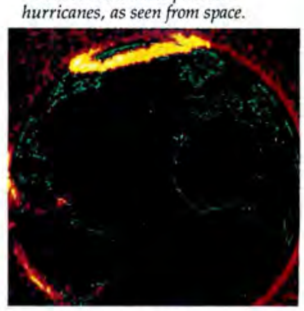




Molten lava rock continually reshapes the Earth's surface.



Earth's rotation helps create hurricanes, as seen from space.



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The Observatory

The Non-Disposable Planet

There's no place like home.

By Thor Heyerdahl

While nobody today is planning our global future, there is no lack of prophets. A generation ago they were nearly all optimists. But today, at the very time when we plunge into the technological era with almost fairy-tale visions of a totally artificial, man-made world designed for Man alone by science, science itself begins to understand the still more incredible composition of the world's ecosystem. Destroy it, and we cut off the branch we sit on. Mankind is at a crossroad, and the prophets are divided between the optimists who hope that man can soon move up to chromed paradise platforms in space, and pessimists who believe we will all be blown up there by a nuclear holocaust.

At the moment, the dreams of a life in space have a magic grip on the world. We all have, and with good reason, a great admiration for the technological brainwork that has made it possible for courageous men to depart from this planet, and for some even to walk on the Moon. Human curiosity will keep us moving ahead, exploring space as far as we can reach from our planet. Possibly this may bring us some material benefit, and probably those who can afford to pay may be entertained by tourist flights to the Moon one day in the future.

But this legitimate fascination with space must not lead us to teach future generations that our own planet has less to offer than its uninhabitable companions traveling around the same Sun. We know already that in our Solar System there is none to equal planet Earth, or to replace it. We must not let our technological successes sweep us completely off the ground.

That seems to happen, however. We devour books and films on imaginary space travels to marvelous planets. We entertain ourselves and our children with space cartoons of interplanetary wars, and we dream of visitors from outer space. At the same time, the real astronauts, American as well as Russian, who come back from space spare no superlatives in describing what a true jewel of a planet we live on here on Earth, compared to the lifeless sands and molten lava to be found elsewhere in our Solar System.

Thanks to communications from unmanned spacecraft, we know that other planets within human reach are obviously uninhabitable for human beings. Nevertheless, there is today a growing number of impractical space dreamers telling the youth and the uninformed that man's future is above the clouds. They tell us not to worry, for if we mess things up too badly here on Earth, we can always move up onto man-made platforms in outer space.

But can we?

With the exhilarating speed of technological progress since the days when Lindbergh flew his modest plane across the Atlantic, it will undoubtedly be possible one day for wealthy nations to send up parts to build large platforms in space, mini-planets like the oil drilling rigs in the oceans, with sterile soil and plastic flowers. But the space immigrants will soon come down and ask farmers on the ground for earthworms and bacteria to prepare their sterile soil for vegetables. Water would have to be hoisted up from the clouds, for rain is made to fall down on Earth. When the oxygen tanks were empty, additional platforms would have to be built with space for trees and leaves to secure refills for the breathing masks. In short, the immigrants up in their cramped quarters would soon regret the money and efforts wasted to be exiled in outer space.

Let us help all those we educate to face a realistic future. Let us encourage them to continue exploring wherever anything can be explored. But let us give them noble ideals and feasible dreams. We ought to prepare those who will take over this planet tomorrow for a healthy way of survival, with both feet planted firmly on fertile ground. □

Thor Heyerdahl is an anthropologist, explorer and author of Kon-Tiki *and* The Ra Expeditions. *This excerpt from his speech upon receiving the 1986 Charles A. Lindbergh award is reprinted by the author's permission.*

NOTES FROM EARTH

Say Cheese

Some of the most memorable photos from Voyager's historic 12-year tour of the outer Solar System were the parting shots taken by the spacecraft as they left each planet behind. Now, as the Voyagers head out of the Solar System, they'll snap one last backward-glance picture—a group portrait of all the worlds they passed on their way out.

The idea to have Voyager take a "family portrait" of the Solar System first surfaced in the early 1980s, and has been championed in recent years by Carl Sagan. Voyager is the first camera-equipped spacecraft able to "stand back" and view all the known planets from a distance.

"The family portrait is a milestone," says Rex Ridenoure, a mission planner for Voyager at NASA's Jet Propulsion Laboratory. "It will be the first time it's been done and the last time it can be done first."

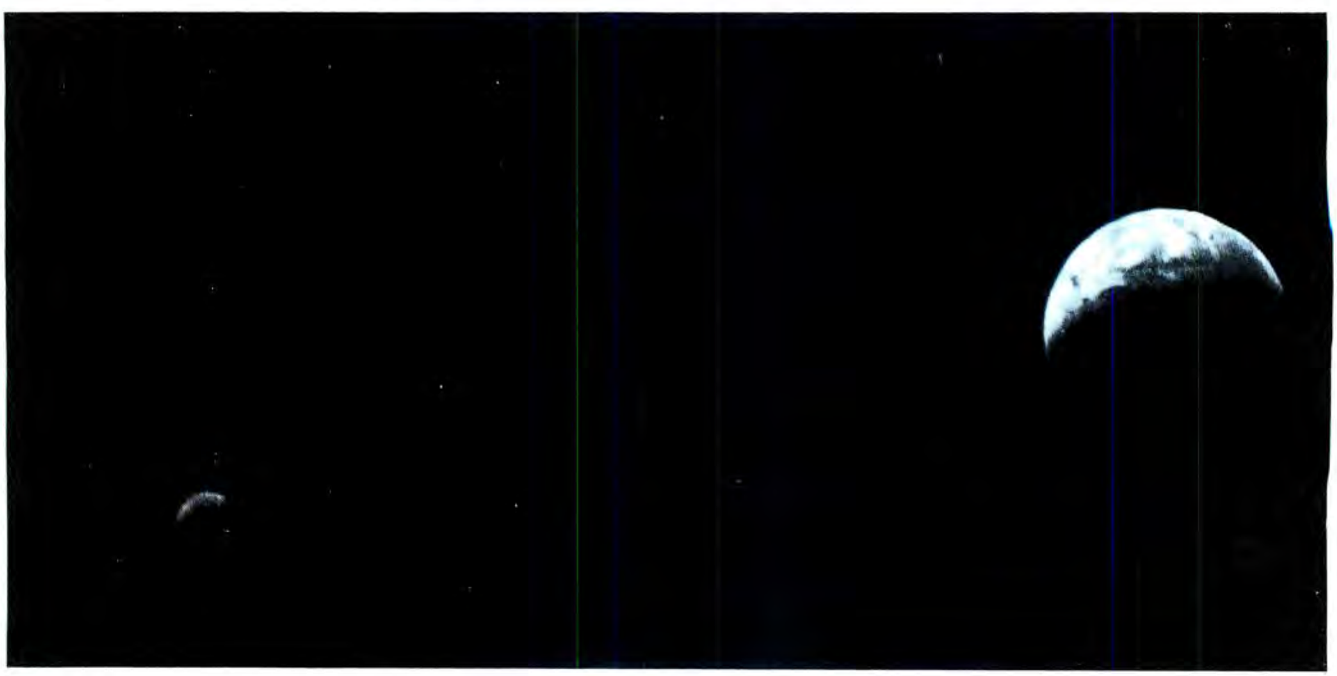
The family portrait will be compiled from a dozen or two individual frames taken by Voyager 1, which saw its last planetary action at Saturn in 1980 (Voyager 2 is unable to move its cameras in the required way to make the photo, Ridenoure says). Not all the planets will be visible, and those that are will appear as tiny crescents. Pluto won't be seen because it's too small and dark, and Mercury's closeness to the Sun will keep it out of the lineup. The dark hemisphere of Mars may also keep that small planet from showing up.

The family portrait session is scheduled for Valentine's Day, February 14, but a little more than a month will pass before the results are in hand. The images will be stored on Voyager's tape recorder and transmitted back to Earth, a little bit each day, from March 16 to March 24. "We won't have anything until the end of March," says Ridenoure.

The family portrait will be the last picture show from Voyager 1. Once the session is over, the spacecraft's cameras will be turned off as it continues into interstellar space.

Are the dim, distant photos even worth taking? "I first heard the three schools of thought regarding the 'family portrait' from a co-worker," says Ridenoure. "It will please those who think it's a waste of time, since the planets will be difficult to see. It will please those who think it will have a philosophical effect. It even will please people who don't care one way or another.

"Either way," Ridenoure says, "It will be the most satisfying picture Voyager has taken, since it will please everyone."—*Joseph Baneth Allen*



Voyager 1 snapped this photo of the Earth and Moon in 1977.

Monkey See, Monkey Do

NASA has flown monkeys in space before, both as "stand-ins" for astronauts (remember Ham, the chimpanzee?) and as experimental subjects (most recently, on the Spacelab 3 mission in 1985). But the most those animals

did—if they were required to do any tasks on their voyages at all—was push buttons. That's because researchers thought primates, and rhesus monkeys in particular, could learn a task only if it required

GEORGIA STATE UNIVERSITY

Video-adept monkey: testing the mental effects of spaceflight

them to use their hands directly. While the monkeys could learn to push buttons to solve a problem, so scientists believed, they couldn't learn the more abstract task of moving a joystick to control a cursor on a video screen.

Recent research at Georgia State University indicates otherwise, however. In an experiment funded primarily by NASA, two rhesus monkeys were taught to control a joystick to respond to computer-generated targets on a video monitor. The cursor's movements were accompanied by a sound to help attract the monkeys' attention. The researchers noted that the monkeys didn't look at their hands as they moved the joystick; they watched the screen. In fact, one of the monkeys became so good at the "game"—which involved moving a white ball to the borders of a dark screen to get a food reward—that when a broken joystick began moving the cursor in the opposite direction from normal, his performance hardly suffered.

"It's been established in the literature for about 30 years that rhesus monkeys' learning is very dependent on hand contact with relevant stimuli," says Duane M. Rumbaugh, director of the university's Language Research Center and one of the study's authors. "That's not true. It's a matter of attention. If their attention can be directed toward the relevant cues, they learn just fine."

The breakthrough is significant for NASA because it means rhesus monkeys can now be used for psychological as well as physiological testing in space. Video tasks can be used to study the effects of spaceflight on a monkey's learning, eye/hand coordination, memory, reaction time and vigilance. Rumbaugh, who is also a regents' professor of psychology at Georgia State University, is now developing a battery of 20 such tests to be tried for the first time on a 1993 shuttle/Spacelab flight.

The video tasks also have one other benefit—they help to keep the monkeys stimulated during a long spaceflight, instead of, as Rumbaugh says, "bored to tears." *—Devera Pine*

Back To Basics

Planners and dreamers often describe a future in which humans live happily ever after on the Moon and Mars in fancy metal cans. But who wants high-tech trailer parks on the Moon? Award-winning California architect Nader Khalili has a better idea.

Khalili has spent years building low-cost housing on Earth using rocks, soil and heat sources. The result has been new housing for the poor, a commendation from the United Nations and, perhaps, a method for building lunar homes.

NADER KHALILI

Add heat, and lunar magma becomes lunar architecture.

Khalili's plan for Moon housing, like his Earth-bound dwellings, is derived from technology developed 4,000 years ago. The construction materials are already on the lunar surface—Moon dust and rocks. Add a source of heat, such as microwaves or focused solar rays, and the resulting magma can be cast or tunnelled to create soaring domes and arches. Khalili even proposes using a giant "potter's wheel" to create graceful ceramic forms in the Moon's one-sixth gravity.

"Sometimes I get so excited thinking about it, I can't sleep," he chuckles.

By using such innovative techniques on the Moon, says Khalili, the design of a lunar base would be limited "only by the human imagination." As a bonus, the building process would create textures and hues that would be unearthly, but pleasing to behold. "All the colors of the rainbow are hidden in the gray Moon dust," muses Khalili.

Both NASA and the International Space University are interested in Khalili's ideas for lunar housing, but he's practical enough to predict that they won't be used for the first Moon settlement. And while he realizes that the commercial potential of his vision is probably limited, the bottom line isn't his driving force:

"It is good to remember," says Khalili, "that what we may ultimately reach in space...may be the space within."

—Mary O'Neill

Planetenteleskop

With the Galileo and Magellan spacecraft speeding toward their respective encounters with Jupiter and Venus, and with still more projects on the drawing board, planetary exploration is back in full swing in the 1990s. One of the most productive of all the planned projects, according to Michael Belton of the Kitt Peak Observatories in Arizona,

NOTES FROM EARTH

could be a comparatively small and unheralded European-American instrument called "Planetenteleskop," known more formally as the Orbiting Planetary Telescope (OPT). Unlike the other "missions," however, OPT would never leave Earth orbit.

The Hubble Space Telescope (HST) will provide us with a powerful new view of the universe, but it's designed primarily for looking at faint and distant astrophysical objects, and will be used sparingly for exploring our own planetary neighborhood. The Planetenteleskop, which was conceived as a West German project in 1986, would be designed specifically for Solar System study.

Planned for launch into high Earth orbit by a Delta 2 rocket in 1998, the modest, one-meter aperture of Planetenteleskop would be less than half the size of Hubble. But it could collect images, infrared and ultraviolet spectrographs all at once—a handy trick that HST cannot perform. Taking pictures at the rate of one a minute, it could investigate, among other things, how the surface and atmosphere of Mars interact, how the volcanoes and atmosphere of Io affect the environment of Jupiter and what makes comets tick.

With an overall price tag of $400 million, Planetenteleskop is now a cooperative project involving the European Space Agency, NASA and West Germany. NASA would handle the launch and the spectrometer packaging, with a $100 million share of the cost—less than the price of a single space shuttle mission.

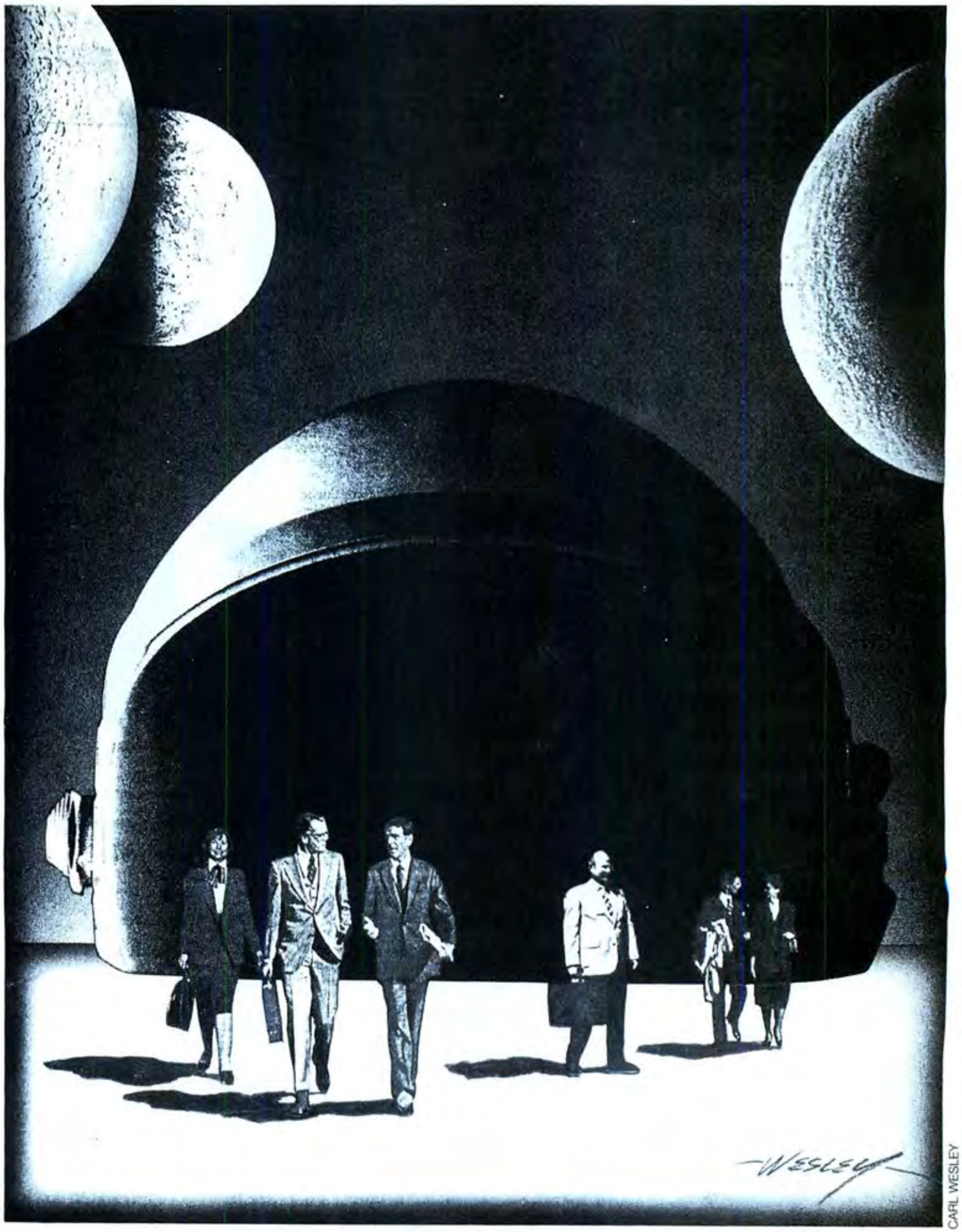
Spinning high above the Earth in an elliptical geosynchronous orbit, OPT could accommodate as many as 500 scientists in the United States alone with up to 12 hours continuous observing time. NASA, says Belton, could coordinate observations with comet or asteroid flyby missions—or even human missions to Mars or the Moon. While these probes or astronauts would be sent to study the "trees," OPT, with its remote observation capabilities, could keep a watchful eye on the whole forest.

—Ray Spangenburg/Diane Moser

Lawyers Aloft

If, as the saying goes, written laws are like spiders' webs, the complexities facing the European Parliament as it moves toward the creation of a single, united Europe in 1992 form a tangled web indeed. Among the volumes of regulations and standards still to be addressed—on subjects ranging from currency to passports—are several issues relating to space.

Enter the European Center for Space Law (ECSL), which grew out of a recognized need to set a legal framework for Europe's rapidly advancing space technology. Founded last spring under the aegis of the European Space Agency (ESA), the ECSL intends "to fill the



CARL WESLEY

large gaps that exist" in coordinating Europe's space laws, according to Gabriel Lafferranderie, an ESA legal adviser.

One particularly complex area involves the regulation of data from telecommunications satellites, whose signals cross national boundaries. The Center is also concerned with intellectual property rights in space and the use of remote sensing information. At a recent international colloquium, space lawyers identified still more problems to be worked out: liability questions in the event of damage caused to or by a space station; management of the international Freedom station; and the legal status of astronauts working in orbit.

To help sort through this tangle, a specialized space law database known as ESALEX has been created to connect users to a single Europe-wide system. Designed to help even non-technical users like students and administrators, the database is "Europe's powerhouse of ideas on space law," said Kevin Madders of ESA's legal department, who manages the ESALEX system.

The database includes everything from international space law texts to national laws and regulations relating to space activities, case laws and reports, legal opinions, acts and proceedings of European organizations, and the complete collection of ESA laws. Access to the network is free to all ECSL members, with the telephone linkup as the only charge.

Speaking of the need to address legal issues as Europe moves into space, ESA Director General Reimar Lust recently said, "We are now in an era when matters of law have a significance to policy makers, investors, industrialists and space agencies alike."

—*C.S. Lambert*

Moonbase #1

If you want to build a Moonbase on Earth, look to Japan for help. That's what the Astronauts Memorial Foundation of Orlando, Florida, did when they decided to construct a privately funded "Moonbase #1" on the "Space Coast" near Cape Canaveral.

In recent years giant Japanese construction companies such as the Ohbayashi and Shimizu corporations have been working on designs for a 21st century lunar base. As a preliminary step, Ohbayashi had planned to set up a simulated Moonbase in Japan. Now it will join in the Florida project instead.

Ohbayashi won't actually build Moonbase #1—foundation officials are negotiating with other U.S. partners to build the facility on some 200 to 350 acres, at a site yet to be determined. But the Japanese company will contribute expertise in such areas as closed loop life support systems, an essential element of any permanent lunar base. Ohbayashi also will help finance the $100 million facility, which will be a center for lunar research and education, according to Foundation vice president Chris Shove.

The Astronauts Memorial Foundation sees the facility as a place to demonstrate such key technologies as robotics, life-support systems, power supplies, construction methods, Moonrovers and mining equipment before a real lunar base is built. The facility could also serve as a tourist attraction, which might be the best way for the Foundation to pay back investors. Shove hopes the ersatz Moonbase will be completed by 1992, in time for the International Space Year.

—*Melinda Gipson*

Earthly Pursuits

Quake Watch

New satellites are helping scientists keep an eye on the restless Earth.

By Hal Smith

When space shuttle Columbia returned to California's Edwards Air Force Base at the end of a successful five-day mission last August 13, it caused more than flags to wave. As the shuttle swept overhead at more than twice the speed of sound, its trademark double sonic booms set off sensitive seismic detectors in the nearby Los Angeles basin, leading to speculation that an earthquake might cause tall buildings in the city's downtown area to sway more than previously expected.

Normally the connection between seismology and spacecraft is not quite so direct. But more and more, researchers are using space data to help improve their ability to understand—and eventually predict—major quakes.

Over the last five years, the Global Positioning System (GPS), a growing network of satellites intended primarily for military navigation, has improved by an order of magnitude the precision with which geodesists—scientists concerned with the size and shape of the planet—can measure the exact location of any point on Earth. By triangulation, the scientists calculate the distance between two or more receivers based on the difference in arrival time of the satellite signals. With benchmarks, geodesists can then track the relative motion of any two receivers.

Beyond its incredible precision (accurate to within a centimeter over hundreds of kilometers), GPS has lowered the cost of collecting this kind of data significantly. Until now, more precise (but more expensive) measurements were available using VLBI—Very Long Baseline Interferometry—which observes distant radio sources, usually quasars, simultaneously with two or more radio telescopes.

San Francisco, October 1989: Satellite data may give us warning next time.

Whereas VLBI requires either stationary telescopes or portable equipment that needs to be hauled around by tractor trailer, GPS uses $20,000 receivers that can be put into a backpack, set up on a surveyor's tripod and operated from batteries. Some geodesists are even looking to the day when miniaturized receivers can be worn like wristwatches. Even now, yachtsmen can buy coarser, navigational GPS receivers no bigger than a lunch box for about $6,000.

Another method of geodetic measurement, called satellite laser ranging, bounces light pulses off small reflecting satellites like NASA's Lageos, which has been in orbit since 1976. Because it requires precise clocks, advanced laser systems and ultra-sensitive optical detectors, this method is inherently more expensive than geodetic measurement using GPS.

NASA, however, has a scheme to improve the cost-effectiveness of satellite laser ranging by putting the most expensive elements of the system in space, onboard the Earth Observing System (EOS) platform planned for launch in 1996. Instead of beaming light up to satellites, the Geodynamic Laser Ranging System (GLRS) would send light down from the orbiting platform to relatively inexpensive, widely distributed reflectors on Earth.

"GLRS is likely to be a much more sophisticated instrument than anything on the ground, resolving vast distances with millimeter precision," says Roger Bilham, a geophysicist at the University of Colorado. This would be a major step forward, provided NASA can deliver as promised, he says. Even though the sys-

tem would be cost-effective compared to current SLR systems, the reflecting mirrors won't be a trivial expense, and protecting them from vandals or severe weather may restrict their distribution more than NASA reckons, Bilham says.

Nevertheless, he is optimistic that advances in space geodesy can help make earthquake predictions more credible. The big question, Bilham says, is whether the instability that precedes a quake develops in zones as wide as the human hand, as some physicists believe, or in zones tens or hundreds of kilometers wide, as several Soviet theorists have argued. If the latter are right, space geodesy may play a major role in improving our predictions.

Precise measurements of the crustal movements that cause earthquakes are adding a new dimension to 100 years of fragmentary research. Even so, considering that some quake cycles may be 300 years long, and that most develop miles beneath the surface, it's a daunting task.

Yet a relatively small investment could quickly advance space geodesy. Although the Department of Defense owns most of the American inventory of GPS receivers, the falling price of the units is making it easier for universities to purchase them, Bilham says. Some are even beginning to show up among surveyors. Meanwhile, 1990 marks the beginning of the Decade of Natural Disaster Reduction and, seismologists hope, a new international willingness to exchange data.

Perhaps nothing better indicates how far space geodesy has come than plans for an expedition barely imaginable a few years ago: An Army team plans to climb Everest with a GPS receiver next year. □

Backyard Universe

Amateur Hour

A few lucky stargazers will soon get to use the Porsche of astronomy.

By Blaine P. Friedlander, Jr.

After raising two kids and working five years in the personnel department of an accounting firm, Seattle housewife Ana Larson wasn't about to turn her one life to live into a marathon of soap opera-watching. Instead, Larson will hunt massive proto-planets using the most sophisticated instrument in the history of astronomy. At the same time, she is earning a double bachelor's degree in Physics and Astronomy from the University of Washington.

"I took a physics course so I could teach science," Larson explains. "I wanted to go back into teaching, and I discovered that I really like physics."

Three years ago, while working on her degrees, she responded to an invitation for amateur astronomers to use NASA's orbiting Hubble Space Telescope, scheduled for launch this April . Larson submitted her idea—a search for solar systems in the process of formation—to the Space Telescope Science Institute in Baltimore, which directs the scientific use of the telescope.

Viewing time with Hubble will be a scarce and coveted commodity, even among professional astronomers. In 1986, Riccardo Giacconi, director of the Institute, offered part of his own "discretionary" viewing time—about 20 hours in all—to amateurs. The call rang throughout the amateur astronomy community, and several hundred responses came from behind hundreds of reflectors, refractors and star wheels. Last August, five of the proposals were chosen.

Ray Sterner, a computer scientist at Johns Hopkins University, will train the telescope on mysterious luminescent arcs seen around galactic clusters, trying to determine if they are optical illusions caused by gravitational lenses, or, as he believes, real phenomena.

Barring last-minute problems, Hubble will get off the ground in April.

A science teacher from the Rochester, New York, area, James Secosky, will look for frost on Jupiter's moon Io, while Theodore Hewitt, a Berkeley, California, science museum volunteer, awaits a nova to study how such a stellar explosion might affect the cloud of comets surrounding a star.

These viewing programs will be fed into a computer in Baltimore, which ultimately determines where the telescope will point. Professional astronomers will help the amateurs analyze their information, and the gathered data will be collated and published in a scientific journal.

Long before he dreamt of publishing scientific papers, Pete Kandefer took his first serious look at the heavens.

"I was lucky enough to have seen Sputnik," he said. The Soviet spacecraft sped across the American sky, while ground observers calculated its position. Kandefer grew to love the sky. He graduated to stronger telescopes, then on to membership in local astronomy clubs. Now he'll get to use astronomy's ultimate "eyepiece." The electrical engineer from New Hartford, Connecticut, hopes that his experiment will contribute new information on the magnetic properties of a particular class of variable star.

"In the end it was all worthwhile," Kandefer said of the two-year wait to hear if his proposal was accepted. "Now, I get a chance to build. It's like launching a satellite of my own."

Like many outstanding amateur astronomers, Kandefer shows off the stars in regular viewings to his local community. Besides using optical telescopes, he also has applied his electrical engineering talents to building a small radio telescope to detect radio interference caused by the Sun. That earned him an award at Stellafane, the annual summertime sky-gazing confab in Vermont.

Each of the five amateurs was notified by telephone that their Hubble viewing proposal had been selected.

"I was excited for two hours," Kandefer said. Many friends don't understand the importance of being chosen, he says, but his astronomy friends do. They know that a backyard stargazer being awarded viewing time on the Hubble Space Telescope is like going to the prom on your first date and having unconditional use of your parents' new Porsche. Maybe even better. □

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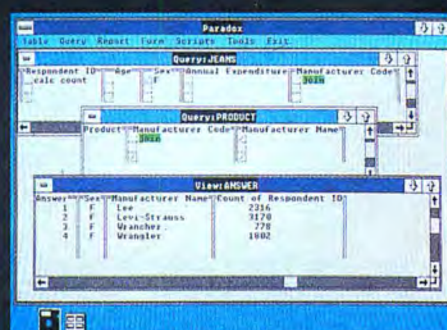

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Space Tech

Raise the Lifeboats

What comes down may also go up.

By Dan W. Leonard

Imagine you've finally made that move to your dream island off the coast. Now only one thing stands between you and the safe, comfortable life you've planned for yourself: a reliable way to get to and from the mainland. You decide to buy a life raft for emergencies. But while shopping around, you spot a beautiful, pricey new cabin cruiser. You can barely afford your island home as it is, much less a new boat. But, boy, would it make things easier—not to mention safer. What to do?

That's what NASA space station administrators are asking as they weigh the merits of a low-cost capsule versus a new miniature space shuttle to serve as Freedom's "lifeboat." In an emergency aboard the station, the proposed rescue capsule would simply fall to Earth. The proposed mini-shuttle, or Personnel Launch Vehicle (PLV), could *coast* back like a glider. More importantly, it also could be launched back up to the station with a crew aboard, greatly reducing Freedom's dependence on the space shuttle.

"There is definitely a legitimate need for a space station vehicle with *down* capability, but is it also necessary for that vehicle to have *up* capability?" says Delma C. Freedman, of NASA's Langley Research Center. "That's one of the things we're trying to find out now."

As head of vehicle analysis, Freedman is leading the team developing the PLV concept, which is competing with three capsule designs for a parking place on the space station.

At a minimum, NASA wants a vehicle capable of safely returning sick or injured Freedom crew members to Earth in the event that the shuttle is grounded. Both the capsules and the PLV could do that. But the PLV also could rescue astronauts stranded during spacewalks, ferry crew members (and cargo) to and from the station, or rescue a visiting shuttle crew if the shuttle malfunctions while docked.

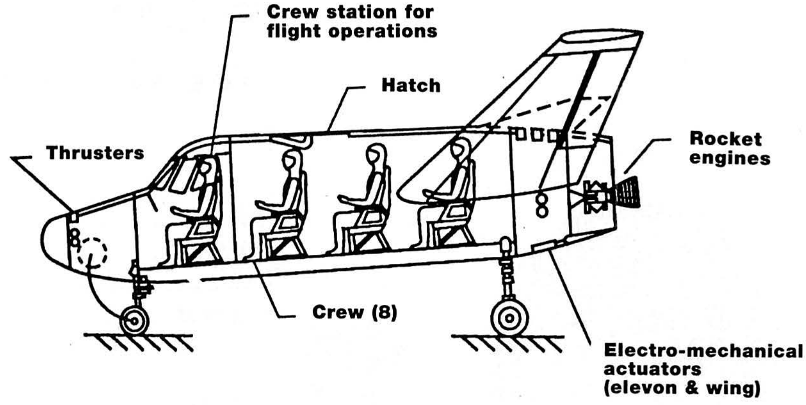
Even without launch capability, a rescue vehicle with some aerodynamic lift is still desirable, says Freedman. A lifting-body vehicle would re-enter the atmosphere at a maximum deceleration of 2 g's, while a capsule re-enters at 4 to 8 g's. Although a healthy person can withstand 8 g's, someone with a broken leg or a ruptured appendix might suffer pain under such a stress.

A lifting-body also offers more flexibility in returning to Earth, Freedman says. While a capsule would fall along the same path in which it was orbiting, a lifting-body rescue vehicle could land anywhere within 900 miles of the space station's ground track, offering more options for reaching suitable landing sites.

The proposed PLV would be 25 feet long with a 21-foot wingspan, a mere dwarf compared to the 122-foot by 78-foot space shuttle. It would weigh 13,500 pounds empty and have room for eight crew members, or four crew members and 1,000 pounds of cargo.

With slight modifications, the PLV could be launched atop a Titan 4 booster, or it could fold up its wings and catch a ride in the shuttle's cargo bay. On the return trip, it would de-orbit with a pair of rockets each having 870 pounds of thrust.

The PLV would be both a lifeboat and a ferry into orbit.



DIMENSIONS AND WEIGHT
Wing span-20.90 ft / Length-24.56 ft / Height-5.70 ft / Gross weight-15,000 lb

It also would have a set of 25-pound thrust reaction control rockets.

The 1950s-throwback, Buck Rogers design of the PLV—round and squat, with stubby wings—is driven by three major criteria. First, the craft needs suitable gliding capability for flexibility in the choice of landing site and lower g's on re-entry. This mandates the wings.

But it also must be very stable aerodynamically so it can fly autonomously, and it must be big enough to hold eight crew members, yet small enough to fit inside a shuttle's cargo bay. These needs led to the rounder shuttle-shaped design, rather than the long, sleek, jet-like design of a miniature National Aerospace Plane, which would have been bigger, but would have had less volume inside.

The PLV is a strong contender to be Freedom's lifeboat, but plenty of people at the ends of the purse strings also are pulling hard for one of the three cheaper capsule designs. Freedman won't give specific cost or contractor projections, but says the PLV's cost would be proportional to a scaled-down shuttle.

While Rockwell International takes over the detailed design of the mini-shuttle, Freedman will turn his efforts to showing that the PLV is economically feasible. "The PLV design is viewed as the Cadillac of the crew rescue vehicle world—more expensive, but also having more capability," he said. "What we're trying to determine now is how much more you have to pay to get that extra capability."

Freedman and his team will have another year to prove the PLV's worth before NASA and a coalition of competing contractors make a final decision. □

MISSION FILE

STS-32

LAUNCH:
7:35 a.m. EST, January 9, 1990
Pad 39A, Kennedy Space Center, Florida
LANDING:
1:35 a.m. PST, January 20, 1990
Edwards Air Force Base, California
ORBITER: Columbia
ALTITUDE: 145-191 nautical miles
CREW:
Daniel C. Brandenstein, Commander
James D. Wetherbee, Pilot
Bonnie J. Dunbar, Marsha S. Ivins, G. David Low, Mission Specialists
PRIMARY PAYLOADS:
SYNCOM IV-5 communications satellite
Long Duration Exposure Facility (LDEF) retrieval
OTHER PAYLOADS:
Fluids Experiment Apparatus
Protein Crystal Growth experiment
American Flight Echocardiograph
Characterization of Neurospora Circadian Rhythms
Latitude/Longitude Locator
Mesoscale Lightning Experiment
IMAX camera

"LDEF is coming home!" proclaimed NASA's new fact sheet about the Long Duration Exposure Facility, an 11-ton "passive" satellite with 57 science and technology experiments onboard. Unfortunately, that was true whether the space agency did anything or not; falling out of the sky at the rate of a half-mile per day, LDEF would have re-entered and broken up in the atmosphere by mid-March. The prime objective of STS-32 was to make sure it returned safely stored in Columbia's payload bay rather than as charred pieces of aluminum in somebody's backyard.

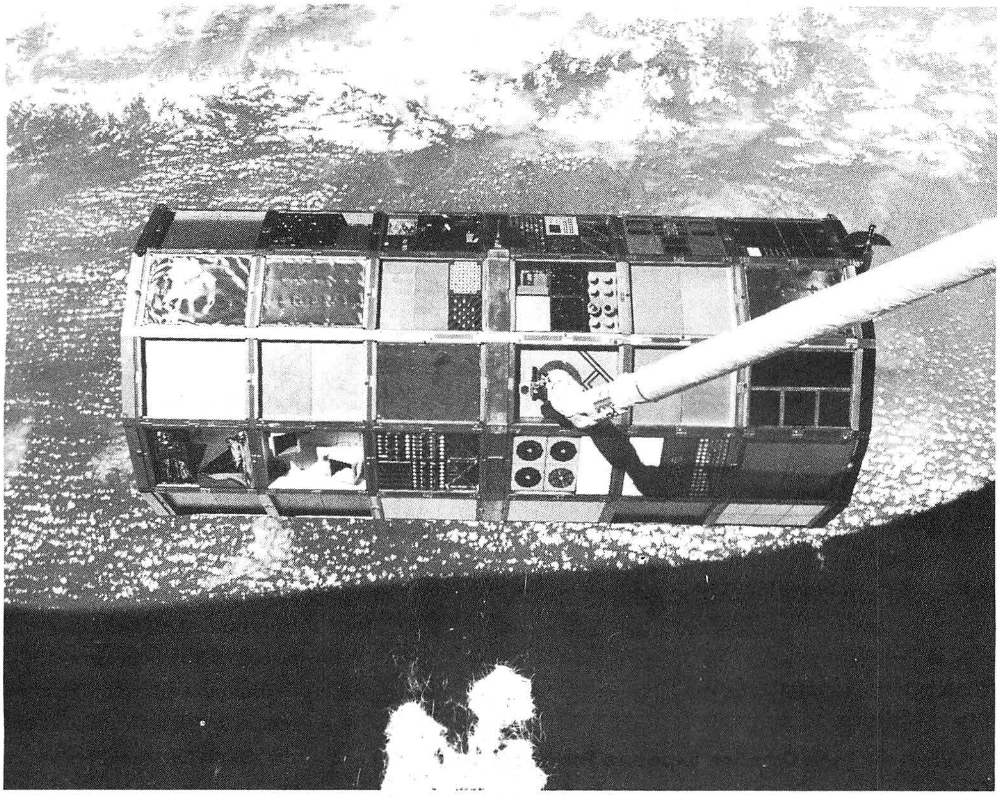
Problems with putting the finishing touches on the remodeled launch pad 39A delayed the mission three weeks past its scheduled mid-December liftoff. But when Columbia finally roared off the pad shortly after dawn on January 9, observers were treated to one of the most visually striking launches ever as the shuttle stack arched through wispy cloud layers painted by the early morning sunlight.

Shuttle veteran Dan Brandenstein's crew had an easy first day in space. Mission specialist Bonnie Dunbar gave Columbia's robot arm a thorough workout to ensure it was ready to snare LDEF three days later. The astronauts also fired the orbiter's engines to move laterally into LDEF's orbital plane— much the way a car changes lanes on a highway— and to slow the rate at which they were closing on the satellite.

On their second day in orbit, Dunbar and David Low (son of George Low, one of NASA's top managers during the Apollo era) successfully launched the SYNCOM IV-5 communications satellite. Rolled out of Columbia's cargo bay using the "Frisbee" deployment unique to the shuttle, SYNCOM rocketed itself to geosynchronous altitude, where it became the fourth operational satellite in a Department of Defense communications system linking ships, planes and ground stations.

Over the next two days, Columbia crept ever nearer to LDEF. The STS-32 rendezvous was one of the most complex the shuttle had ever attempted, requiring 11 major firings of Columbia's maneuvering engines. During one of the burns, the astronauts let viewers on the ground watch over their shoulders via a TV camera mounted in the aft flight deck. Surprisingly, the engine ignition didn't produce much of a visible kick—just a brief jiggle in the picture, much as if the 100-ton orbiter had hit a pothole in the road.

During the final phase of the rendezvous on the morning of January 12, the astronauts used a new maneuver called "minus R BAR" that eliminated the need for a close-in fly-around of the target. In a cos-



"Gotcha": After almost six years in orbit, LDEF was grabbed by Bonnie Dunbar using the shuttle's robot arm. Opposite: Brandenstein, Dunbar, Ivins, Low and Wetherbee onboard Columbia.

mic *pas de deux*, Columbia passed about 3000 feet beneath LDEF, swooped up to a position 400 feet directly *above* the satellite, then moved straight down the radius ("R BAR") line passing through LDEF toward Earth.

Dan Brandenstein, known as one of the best "stick men" among shuttle pilots, nudged the orbiter down a few feet at a time while Bonnie Dunbar poised the robot arm to capture LDEF. When the school bus-sized satellite was lined up just 35 feet away, Dunbar deftly brought the arm's "end effector," or hand, five feet forward and grappled one of LDEF's docking fixtures.

"We have LDEF," Brandenstein radioed proudly to Mission Control. "Everything went just the way a nominal sim [simulation] does—only the visuals were better!"

For the next four and a half hours, Dunbar manipulated LDEF though seven different positions while Marsha Ivins took still photographs and videotape. The photo survey documented the condition of LDEF's experiments after almost six years in orbit, in case the satellite sustained damage during reentry or, even worse, couldn't be locked into Columbia's payload bay and had to be re-boosted to a higher altitude.

Later that afternoon, Dunbar again showed her dexterity with Columbia's remote manipulator arm. Using almost imperceptible movements—sometimes as little as a tenth of a degree at a time—she guided LDEF into the open payload bay, which had only six inches to spare on either side of the bulky satellite. Once LDEF was perfectly aligned, four latches on the cargo bay walls and one on the keel locked the craft firmly into position for the ride home.

With their main goal accomplished, the astronauts concentrated on the battery of scientific and medical investigations mounted in Columbia's mid-deck cabin area. STS-32 was the second shuttle flight for the Fluids Experiment Apparatus (FEA), a device to grow pure crystals in microgravity. During each experiment run, the FEA used a moving heater to produce a "floating melt zone" in a sample of pure indium. This flight was aimed at learning the effects of routine mission activities on crystal growth. A special accelerometer connected to the experiment recorded disturbances caused by firing of the orbiter's thrusters and by astronauts exercising on a treadmill. "You could tell the molten zone was undulating while Dan was running," reported David Low. "It's pretty dramatic."

The Protein Crystal Growth (PCG) experiment was designed to produce 120 crystals with 24 different proteins. Researchers want to determine the proteins' three-dimensional structure as part of studies that could lead to improved pharmaceuticals. The PCG experiment had a rocky start, however; the astronauts discovered that one of the trays somehow came unplugged during their first night of sleep, and experimenters were unsure what effect the resulting rise in temperature would have on that batch of crystals.

One of the niftiest gadgets the astronauts used on STS-32 was the Latitude/Longitude Locator, also known as "L-cubed." As Columbia flew over specified sites on Earth, the astronauts used a camera connected to a computer to snap photos of the target at 15-second intervals, while the computer generated two possible latitude/longitude readouts. The L3 could be especially useful on future missions to pinpoint the exact location of ocean features seen from space.

The STS-32 crew also had a variety of medical tests to do during their scheduled ten days in orbit—twice the length of most shuttle flights. With 16-and 28-day missions in the works for 1993 and beyond, NASA doctors wanted the extra time to renew studies of how lengthy stays in space affect the human body.

A slight glitch plagued the American Flight Echocardiograph (AFE), an off-the-shelf ultrasonic imager that displays two-dimensional video of the heart and other organs. Mission specialist Marsha Ivins noticed that electromagnetic interference distorted the half of the screen she used as a monitor, although the AFE images

picked up by an onboard camcorder were fine.

The AFE also was used with a collapsible Lower Body Negative Pressure (LNBP) unit that made its debut on STS-32. The accordion-like, barrel-shaped device is designed to pull fluids toward an astronaut's legs after he or she drinks a controlled amount of saline solution. Bonnie Dunbar and David Low each took several turns in the experiment during the latter half of the mission, including "therapeutic" runs that kept their lower bodies at negative pressure for four hours. Researchers believe that even simple countermeasures such as the LBNP may help astronauts re-adapt to gravity while still in zero-g.

At times, Columbia itself needed some therapeutic treatment. NASA's first space shuttle seemed to be afflicted with more than the usual number of electromechanical aches and pains. During a routine inspection, commander Dan Brandenstein discovered water seeping from one of the humidity separators located beneath the orbiter's mid-deck floor. The astronauts quickly mopped up "the bilge," but the problem persisted throughout the flight. Eventually they resorted to a low-tech solution, wrapping the unit in a towel to sop up the moisture.

False alarms went off nearly every day. One of Columbia's three Inertial Measurement Units (IMUs) went off-line when it erroneously reported a shift in acceleration. And during the mission's last few days, a faulty smoke detector buzzed the astronauts awake several times.

More serious was an error made by Mission Control on January 17, when an incorrect "state vector"—navigation information used by the orbiter's computers—was radioed to Columbia. As a result, one of the orbiter's small maneuvering engines fired while the crew slept, causing the shuttle to roll at three degrees per second. Ground controllers woke commander Brandenstein, who manually returned Columbia to its proper attitude.

Brandenstein, who heads NASA's astronaut office, passed a couple of milestones during STS-32. He took a deluge of good-natured ribbing for reaching his 47th birthday while in orbit. He also figuratively became the "old man" among shuttle astronauts when he eclipsed Bob Crippen's record of 565 hours in space.

Bonnie Dunbar also had reason to celebrate. She broke the record for time-in-orbit by an American woman, and learned that NASA had tapped her husband, Ron Sega, as a member of the latest astronaut class.

Columbia was scheduled for a pre-dawn landing at Edwards AFB on January 19, but ground fog caused Houston to "wave off" the attempt for an extra day. The next morning, Brandenstein and pilot Jim Wetherbee finally brought Columbia and LDEF home, making a smooth touchdown on Edwards' concrete Runway 22. To compensate for the hefty LDEF sitting far forward in the orbiter's cargo bay, Brandenstein landed at a faster-than-normal speed and held the spaceplane's nosewheel off the ground for a few extra seconds.

The landing delay made STS-32 the longest shuttle mission to date, passing STS-9's 10-day, seven-hour mark. The real significance of the flight, however, was that NASA again proved its point about the shuttle: if you want to "pick up"as well as "deliver," it's the only way to fly. □

LDEF COMES HOME

When the Long Duration Exposure Facility was released into orbit by the STS-41C astronauts in April 1984, NASA expected to have it back on the ground within a year. Because it was stranded in space for almost six times that long, scientists and engineers expect the 57 experiments onboard the satellite to yield a bonanza of data useful in designing spacecraft for long stays in orbit.

NASA won't release full results of its study of LDEF until mid-summer, but program officials were unanimous that the satellite appeared in much better condition than expected, based on video images sent back during the photo survey in orbit.

The end of the craft that was pointed in the direction of its orbital motion showed the greatest wear and tear. One of the materials experiments mounted on panels fixed to the satellite's exterior was "peeled back like a sardine can," in the words of one astronaut. Shuttle commander Brandenstein noted that LDEF was surrounded by minute pieces of debris that presumably had flaked off during the retrieval operations. Also, some experiment doors that should have closed at the end of LDEF's nominal one-year period in space apparently stuck open.

Researchers were especially anxious to get their hands on thin-film materials such as Kapton to determine the effects of atomic oxygen deterioration. In some cases, only 1 mil of material was estimated to be remaining on sheets that had been 5 mils thick.

And schoolchildren across the country awaited their share of the 12 1/2 million tomato seeds that flew on LDEF as the Space Exposed Experiment Developed for Students (SEEDS). Although the seeds were saturated with radiation—leading to innumerable jokes about "Killer Tomatoes"—experimenters believed that some of them will sprout and produce fruit.


NASA/PAUL HUDSON

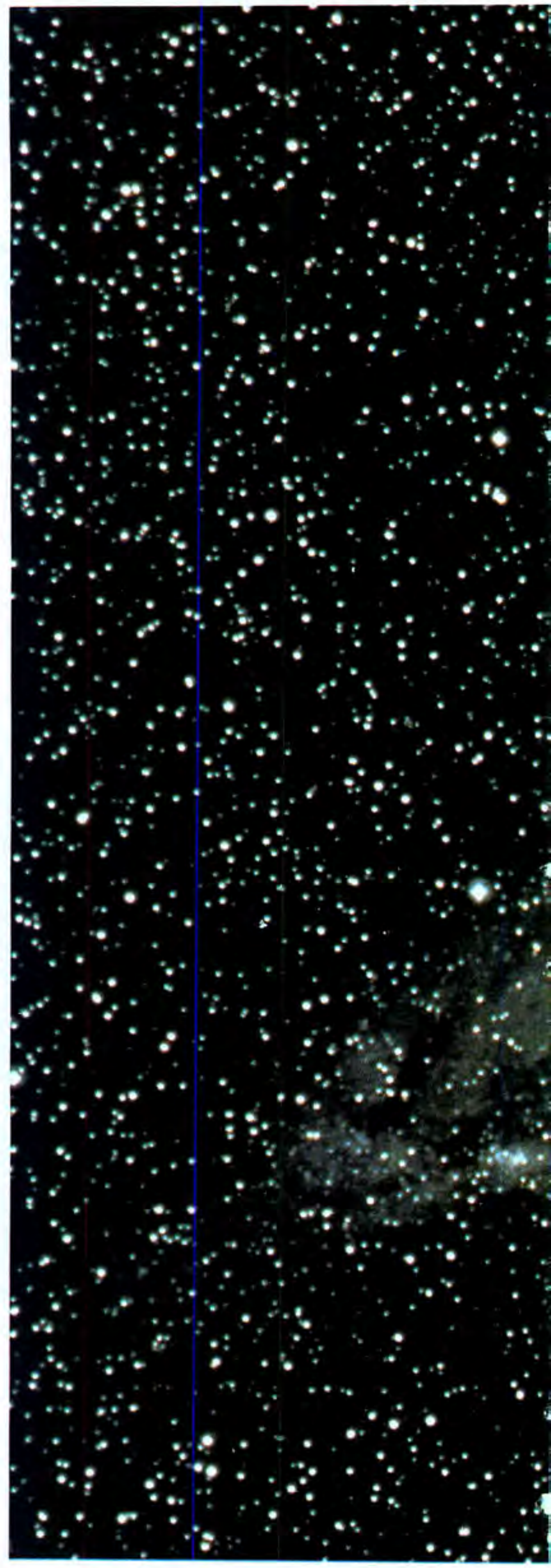
It won't see the Restaurant at the End of the Universe, but it will show us just about everything else. By Andrew Chaikin

From our little corner of the universe, at the inner edge of the Orion Arm of a spiral galaxy called the Milky Way, we are about to take a good look around, at last free of the murky window we call the atmosphere. The Hubble Space Telescope isn't very big as telescopes go. Its instruments are based on decade-old technology. It is hellishly complex to operate. Even its proponents caution that parts of it are likely to break down when it is in space. But even if it doesn't work as well as expected—and most astronomers suspect it will not—it has the potential to transform our comprehension of the universe. The talk you've heard about how it represents the biggest leap in observing power since Galileo invented the telescope, how it could help answer fundamental questions about the universe, is true.

The Space Telescope project is what historian Robert W. Smith calls "Big Science," a massive effort whose initiation required not only scientific but political expertise, and whose history is marked by managerial as well as technological battles. Thousands of scientists and engineers in aerospace companies, universities, and within NASA have participated in the telescope's design, manufacture and testing over a span of nearly two decades. An entire operations and research center called the Space Telescope Science Institute has sprung up on the campus of Johns Hopkins University in Baltimore to manage the telescope's scientific explorations.

But the dream of a telescope in space dates to 1923, when German rocket pioneer Hermann Oberth first described the tremendous advantages of an instrument placed above the atmosphere. By 1946, wartime advances in rocketry had made Earth satellites feasible, and Princeton astronomer Lyman Spitzer took up the cause of a space telescope. That year the 200-inch Palomar reflector, destined to let astronomers look back in space and time almost to the birth of the universe, was still under construction. But even then astronomers knew that it would be limited in what it could achieve. The Palomar reflector's great light-gathering power would let astronomers see farther, but it would not add one bit of *detail* to the view of any celestial object.

It sounds impossible to anyone who has stood in the shadow of one of these glass and metal giants, but it's true: In terms of image sharpness, the largest telescopes perform no better than a good 8-inch scope in the backyard. The reason is simple; they all look



The Space Telescope, The

HST will be able to take a thorough census of stars in the nearby Andromeda galaxy.

Universe and Everything

Right: the Orion Nebula, a stellar nursery some 1,500 light years distant, should show new detail in Space Telescope images. Far right: the shuttle will release the telescope into orbit, then back away while engineers on Earth begin checking out its systems. Astronauts will be able to repair and replace HST's instruments on future visits to the orbiting observatory.

through the atmosphere.

The seemingly clear dome of a dark night sky is anything but a perfect window on the heavens. The air is always in motion, and for astronomers this turbulence takes a heavy toll in detail. The sharp pinpoint of a star's image becomes smeared into a blob of light. The same goes for any small feature, whether a wispy cloud in Jupiter's atmosphere or the starry whorls of a distant spiral galaxy. The degree of atmospheric clarity, which astronomers call "seeing," varies from night to night according to the whims of the atmosphere. And only under the best conditions—a handful of nights per year—can a well-made telescope on Earth approach its theoretical limit of performance.

But in the vacuum of space the seeing is always perfect, and the gain in resolution is astonishing. Another enormous benefit is access to the entire spectrum, not just the narrow range of wavelengths that filter through the Earth's atmosphere. A large orbiting telescope would transform astronomers' view of the universe, and yet, in the 1960s when Spitzer tried to convince his colleagues to support the idea, they balked.

Some doubted such an instrument could be built. But their strongest objections were to its cost. Rice University's C. Robert O'Dell, who served as Project Scientist from 1972 to 1983, remembers a common sentiment: "Wouldn't it be a lot better for us to spend all this money on a row of twenty-seven 200-inch telescopes?" For his part, O'Dell had no doubts. "Clearly, the Space Telescope was going to be the most important telescope built during my lifetime," he says. "And I still

The Soul of a New Machine: FOC, WFPC and CCD's

Swathed in reflective Mylar and weighing in at 25,500 pounds, the 43-foot-long $1.5 billion Hubble Space Telescope is, with the possible exception of the biggest particle accelerators, the most complex scientific instrument ever built. To appreciate the precision of HST's construction, one need only consider its main mirror, a 94-inch Lifesaver of fused silica built around an "egg-crate" silica lattice to save weight. More than two years of computerized grinding and polishing produced a reflecting surface accurate to within two millionths of an inch of the ideal mathematical shape. Coated with aluminum to reflect visible and ultraviolet light, it is the most perfect large optical mirror ever made.

The mirror is the heart of HST, but the rest of the telescope is no less remarkable. A superb mirror would be worthless without an equally exacting support structure to hold it in place. Engineers created a truss out of graphite-epoxy resin that is so resistant to expansion that the telescope will remain in focus even when HST drifts from frigid orbital night into fierce sunlight. But the greatest single technical challenge was the pointing system, whose accuracy is nothing short of staggering.

To appreciate the pointing system, first consider the smallest detail Space Telescope will be able to resolve in visible light: one tenth of an arc second (in other words, 1/36,000 of a degree). That's the equivalent of a person in New York being able to distinguish between the left and right headlights of a car in Los Angeles. HST's pointing system will be called upon to turn the 25,500-pound telescope and aim it within a *hundredth* of an arc second of any point in the sky, and maintain that position to within seven *thousandths*

continued on page 56

NOAO

LOCKHEED

believe that's true."

By the early 1970s, what O'Dell calls "this ill-defined, uncooperative group called the astronomical community" had come around. And the technology to build Space Telescope was coming into existence. But the task of making Spitzer's vision a reality proved to be one of the most difficult, drawn-out struggles in the history of science. In the post-Apollo era of austere space budgets, selling a big-ticket program like Space Telescope to Congress was not easy. Spitzer and John Bahcall of the Institute for Advanced Studies assumed the unaccustomed role of political lobbyists, defending the telescope against the recurring question, "Haven't we spent enough?" O'Dell credits the efforts of Bahcall and other astronomers with getting the project safely through the many funding crises in its history. "Had it just been one of the NASA field centers advocating it," he says, "we would have been dead."

Selling the telescope to Congress turned out to be much easier than keeping NASA from canceling it. With the shuttle program consuming most of the agency's limited allocations, Space Telescope was a stepchild. In late 1975 NASA deleted the project from its budget requests, and the astronomers mounted their most determined campaign of all. Bahcall says one NASA official (now no longer with the agency) threatened him with cutting support to astrophysics research if he didn't call off the fight.

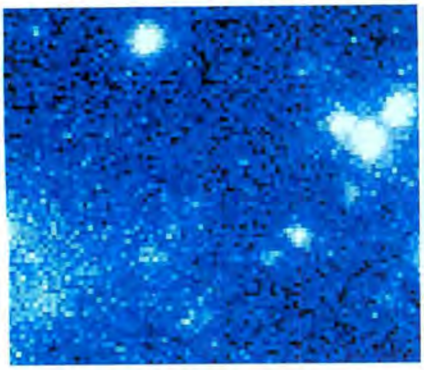
"It was hardball," Bahcall says, "But fortunately, I didn't listen and neither did my colleagues. And in fact, now this program is the jewel in the crown of NASA's Scientific offering."

Like other Big Science projects, the Hubble Space Telescope (HST) has been beset by countless delays. Problems with getting the spacecraft ready for flight forced its launch, originally slated for 1983, to be postponed until late 1986. The Challenger explosion added more than three years to the wait. But the down time turned out to be a blessing in disguise; a number of serious problems came to light during the delay, including a realization that the spacecraft would require more power than expected. Tests showed that after a few years in orbit, once the solar arrays and batteries had begun to degrade, there wouldn't be enough power available for a full program of observations. Project engineers took advantage of the extra time to replace the arrays with newer, more efficient models, and substituted newly developed nickel-hydrogen batteries for the conventional nickel-cadmium ones originally installed.

When HST finally does reach orbit this spring, scientists on the ground will have their hands full running this observatory in space. Scheduling the planned observations will be a continuing headache. Three hundred miles up, whizzing around the Earth once every 95 minutes, HST will face a constantly changing configuration of obstacles between it and the heavens — namely the Sun, the Earth and the Moon. Direct sunlight would destroy the telescope's instruments, which are designed for objects billions of times fainter. So an onboard computer will have strict instructions not to point the telescope closer than 50 degrees from the Sun (eventually planners hope to get within 40 degrees so that HST can observe Venus). Sunlit portions of the Earth and Moon won't cause damage, but would ruin an exposure. So the telescope must not point within 5 degrees of the Moon or 70 degrees of the daylit side of the Earth.

As if these restrictions weren't enough, the telescope will have to shut down each time it passes through the so-called South Atlantic Anomaly, where the Earth's radiation belts dip down to the spacecraft's altitude. It must also avoid pointing into the direction of flight, where it would risk scooping up stray oxygen atoms from the upper atmosphere that would contaminate the optics.

Only a computer could handle the task of scheduling around this cosmic obstacle course. The software for the job, called SOGS (for Science Operations Ground System), was one of the nastiest problems HST scientists had to deal with during the post-Challenger delay. Essentially, the scientists will give the computer a pool of observations they want HST to perform during a given week, prioritized by scientific importance. The system will sort through the list to figure out the most efficient way of getting them all done.



STScI

One of the things SOGS has to take into account is the time needed to turn the telescope toward a given point in the sky. Maneuvering rockets were out of the question for HST's design—their exhaust would have contaminated the instruments. Instead, the spacecraft uses reaction wheels that turn it about as fast as the minute hand on a watch; planners expect anywhere from 5 to 20 minutes for HST to lock onto each new target. With that in mind, and given the fact that targets could be sprinkled all over the sky, the task of maximizing the telescope's efficiency is so complex that another computer will first perform a "coarse" sorting, then hand over the results to SOGS. Herculean effort by programmers has refined the software to the point where it should take only a few hours to build a week-long calendar.

Given the complexity of their task, ground controllers scheduling HST will have to work very hard to get up to maximum efficiency. For the first year or so, the telescope probably will be observing only 20 percent of the time, but planners hope to reach a maximum of 35 percent. If that seems disappointing, it's actually no worse than the situation at many ground-based observatories, which have to contend with clouds, moonlight and, of course, bad seeing.

As HST goes about its business, turning slowly from galaxy to nebula to quasar, ground controllers will occasionally be called on to meet the demands of "target of opportunity" users like Harvard astronomer Robert Kirshner, who plans to use the telescope to study supernovas. As soon as he receives word that a new one has been seen from Earth, he says he'll be on the phone to the schedulers: "Hey, guys—Remember that target of opportunity proposal you approved three years ago? Now I want to cash that check." Kirshner hopes that the telescope would zero in on the newly found supernova within a day or so.

To say the least, observing time on HST will be a precious commodity. About 80 astronomers who gave a decade or more of their lives to designing the telescope's instruments were long ago named Guaranteed Time Observers. In 1983, that select group got together for a meeting they called "Dividing Up the Universe."

"It was done all in the spirit of friendliness," Bahcall says. "I think there were a lot of people who thought it wouldn't work and that people would run away fighting, vowing never to speak to each other again. And the exact opposite happened. Not because human nature doesn't have an element of greed in it, but because we all see that there is so much scientific gold with the Space Telescope." O'Dell headed the selection procedure, and so wasn't eligible, but the others chipped in and gave him some of their time. He then turned around and gave half of it to Lyman Spitzer.

Things were a bit more competitive when it came time for the rest of the astronomical community to submit proposals to the Space Telescope Science Institute (STScI); only one in nine were selected. One astronomer who won time on HST won't give any details on what he's going to do with it, beyond what he wrote in his proposal. "I don't need the competition," he says. "I hate to be hard-nosed about it, but that's the way I have to play the game. I'm in a very competitive business."

That is quite evident when the subject of releasing images to the public comes up. Eric Chaisson, Director of Educational and Public Affairs at the STScI, has raised more than a few hackles with a plan to have HST take a series of pictures for public release shortly after its launch. A single day's worth of press releases, Chaisson says, might include views of the core of the Andromeda galaxy, a globular star cluster suspected to harbor a black hole, a couple of other deep-sky oddities, and just for good measure, views of Jupiter, Saturn and their moons Io and Titan. But STScI policy calls for a one-year waiting period while HST astronomers analyze their data.

"Even though [HST would be] up there and the public would perceive it as unlocking the secrets of the universe, they were simply going to hold the public at bay for months," Chaisson says. "I thought that would be an absolute public relations disaster, and wrong for many reasons."

But while it may help public relations, it could strain relations with some project

KITT PEAK NATIONAL OBSERVATORY

Far left: How HST will sharpen our view: a simulated view of a distant cluster of galaxies as seen with ground-based telescopes (left), and the same cluster as it would be seen by the Space Telescope. Left: Within HST's reach: hundreds of galaxies congregated in the Hercules supercluster, some 420 million light years away. Everything in this photograph that isn't a pinpoint is a galaxy.

scientists. The problem, says one researcher who did not wish to be quoted, is that everything on Chaisson's list is something an astronomer has spent years preparing to observe. "If he immediately releases that information, every Joe Blow can read the newspaper, get out his plastic ruler, and scoop you. And there are people out there like that." (In this case, of course, "Joe" would have to have at least a graduate student's knowledge of astronomy.)

"We're trained to be paranoid as astronomers," Chaisson says. "Because there's no bronze and silver medals in science. Everything is placed on premier, number one release or credit."

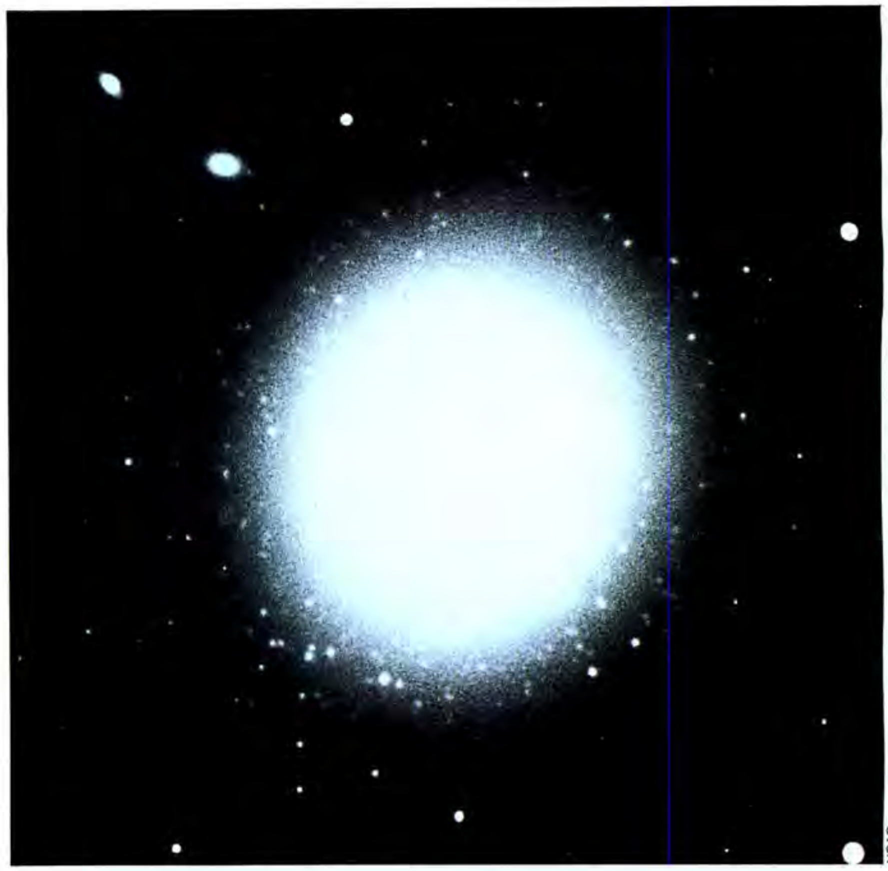
Astronomers call it "First Light"—the moment when a new telescope is turned on the heavens for the first time. For Space Telescope it will come about a day after the spacecraft is released from the cargo bay of space shuttle Discovery in late April. A hinged door on the front of the telescope tube will swing open, and for the first time starlight will fall on the main mirror. Then the orbiting observatory will begin three months of focusing checks, pointing tests and instrument checkouts by controllers at STScI and NASA's Goddard Space Flight Center. It will take weeks for the spacecraft to shed the last vestiges of air and water vapor to the vacuum of space. Until then, controllers will avoid turning on most of the telescope's instruments, which require very high voltages, to avoid the risk of electrical arcs.

The exception is the Wide Field/Planetary Camera (see the description of HST's instruments on page 26). About four days after launch, while engineers are checking the telescope's focus, the spacecraft will be aimed at a rather boring star cluster called NGC 3532 in the southern constellation of Carina, and the WFPC will snap HST's first test images. Even these should be something of a revelation. Caltech's James Westphal, team leader for the WFPC, says, "Our first reaction is going to be, 'Did we point the thing in the right place?' It's not going to look right. There's going to be jillions of stars we haven't seen before."

In fact, the Space Telescope should see plenty that astronomers haven't seen before. While HST can resolve details as small as a tenth of an arc second in visible light (an arc second is 1/3,600 of a degree, and the entire horizon spans 180 degrees), it will do even better at ultraviolet wavelengths, where the telescope's Faint Object Camera will be able to see details nearly twice as small. The numbers are even more impressive when you realize that they apply to both the horizontal and vertical dimensions of a picture. To say that HST's better than one-tenth arc second resolution represents a tenfold increase over ground-based performance is deceptive; in fact, it will yield 100 times more detail.

Nor will it have to contend with most of the scattered light from the weak permanent aurora in the tenuous upper atmosphere that astronomers call the airglow. Even on the darkest mountaintop this glow is bright enough to drown out very faint stars and galaxies. But stars will appear 100 times more compact to HST than they do from Earth, and a smaller image means less airglow when you zoom in on it. As a result, HST will be able to detect objects ten times fainter than any Earthbound telescope, and in many cases that means ten times more distant.

Using a telescope that can peer billions of light years into space to explore our own Solar System seems a little like aiming a backyard telescope at the apartment building across the street. But planetary scientists are very anxious to see what the Space Telescope will show them. Jupiter will be the most popular target, according to Caltech's James Westphal. Pictures of the giant planet made with the Wide



One of HST's most mysterious targets, the galaxy M87, may harbor a black hole the size of the Moon at its center. Above: the galaxy's unexplained jet.

Field/Planetary Camera will show as much detail as those taken by the Voyager probes about five days before closest approach, which is ten times better than we can usually do from the ground. Scientists who study Jupiter's atmosphere will use HST to chart the planet's changing cloudscape on an ongoing basis, building up a valuable record of Jovian atmospheric behavior.

When it's not looking at Jupiter, HST should be able to glimpse volcanoes erupting on the planet's moon Io. Ultraviolet observations of Saturn may reveal cloud patterns beneath the icy hazes of the upper atmosphere, something Voyager could not do. The telescope also will monitor Venus' atmosphere and view the unknown hemisphere of Mercury, the side not photographed by Mariner 10.

At long last, we will even glimpse the face of distant Pluto. But, as Westphal says, "It's going to be a little disappointing." HST's images will show Pluto about as well as we see the full Moon with the unaided eye, "enough so that we can see that there are different colors on different parts of it, which we're pretty sure there are." Whatever they lack in detail, the images will still help answer some important questions about Pluto and its satellite. Astronomers will be able to use Space Telescope images of Pluto and its moon Charon to track the pair's motions, which should allow them to compute masses and densities for both objects. That, in turn, will allow them to infer their compositions: icy, rocky, or both. But on the vast scale of the universe, the distance from here to the edge of the Solar System doesn't even register. The Space Telescope's real hunting ground is far beyond our little neighborhood, out in deep space.

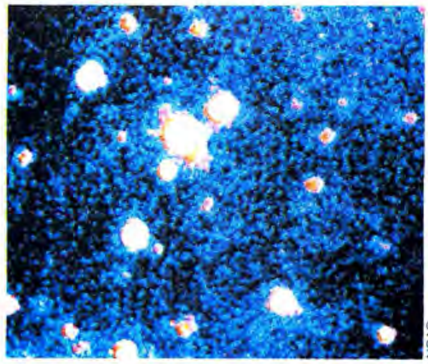
One of HST's more familiar targets will be the Orion nebula, that glowing flower of gas and dust that is a favorite of backyard observers. The nebula is of great interest to professional astronomers because it's thought to be a place where stars are being born. The nebula is rich with detail, some of it beyond the ground-based seeing limit on even the best observing nights. For Bob O'Dell, the thought of turning the Space Telescope on this stellar nursery triggers awe even now. "I just wonder what it's going to look like at ten times better resolution," he says. "I think we're going to see a new object." O'Dell also wants to look at two other well known nebulae, the Owl Nebula and the Dumbbell Nebula. He thinks there may be active comets floating within them, and he wants to see if the Space Telescope can find them. That's something Westphal calls "sporty," but still worth a try: "I wouldn't dissuade anybody from doing almost *anything* with HST, because we know so little about what we're going to see."

There are some things the telescope won't do, like photographing features on the surface of another star. A black hole, of course, would emit no light for HST to detect, but astronomers are unsure whether they might spot the glowing disk of matter thought to encircle it. One of the fondest hopes for HST is that it will detect planets circling other suns. At the very least, the images should let astronomers measure a nearby star's motion with enough accuracy to detect wobbles caused by the gravitational pull of a Jupiter-sized planet. But actually photographing a world in another solar system may be beyond the Space Telescope's grasp.

Within our Milky Way galaxy, HST's instruments will provide new portraits—photographic, spectroscopic and otherwise—of the whole stellar menagerie, including double stars that steal matter from one another by gravitation, neutron stars that spin hundreds of times a second and dwarf stars so small and faint they barely qualify as stars at all.

Even our most basic understanding of how stars evolve should take a leap forward when HST turns its gaze on the globular clusters that hover beyond the plane of the

Right: The Space Telescope could tell us if quasars like 3C 275.1 (the brightest object in this false-color image) are the ancestors of modern galaxies. Far right: HST's main mirror, the most perfect of its size ever made.



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Milky Way, each containing between 20,000 and a million stars. Globular clusters have long been a favorite target for stellar evolution studies, for the simple fact that all the stars in them are the same distance away. With distance effects removed, astronomers can determine the stars' relative brightness with much greater certainty. If one member of the group appears dimmer than another, it really is. But globulars are so crowded with stars that we have only been able to study their outskirts. HST's ability to see stars as pinpoints will alleviate crowding, allowing astronomers to survey the stars in the heart of a cluster for the first time.

One of the greatest single leaps in our understanding of the cosmos came in 1923, when the American astronomer Edwin Hubble succeeded in photographing stars within what was then called the Andromeda nebula. At the time, "spiral nebulae" were thought to be swirls of gas within our own galaxy. Hubble's photographs showed that they were in fact other galaxies, separate island universes.

Although Andromeda is the closest major galaxy, at a distance of two million light years, most of its estimated 300 billion stars escape our scrutiny. It's as if we're looking out at the next town, certain that people live there but unable to learn anything about their ages, professions and activities.

The orbiting telescope named for Edwin Hubble will be able to resolve stars within Andromeda easily. Astronomers will be able to take a thorough census of Andromeda's "residents" for the first time,

continued on page 52

The Great Observatories

In the minds of NASA planners, the Hubble Space Telescope is not the last word in space-based astronomy, but merely the first in a fleet of "Great Observatories." Current plans call for HST, which "sees" in visible and ultraviolet light, to be followed within the decade by three more orbiting telescopes—the Gamma Ray Observatory, Advanced X-Ray Astrophysics Facility and Space Infrared Telescope Facility. Together, these Great Observatories will give us a detailed—and nearly complete—new picture of the universe.

By studying an object in different wavelengths of light, astronomers can gain a fuller understanding of its composition, behavior and history. With all four Great Observatories up and running, astronomers will be able to look at a nearby galaxy, for example, and detect ultraviolet radiation from newly forming stars, gamma and x-rays from dying stars and infrared radiation emanating from low-energy molecular clouds. The *combination* of data is what will help astronomers determine the galaxy's current stage of evolution.

Like HST, all the Great Observatories will have long lifetimes in orbit, with instruments designed to be serviced and upgraded by visiting astronauts. Each represents a tenfold improvement in viewing power in their region of the spectrum, and together they will detect 75 percent of the energy coming from objects in space. Only the microwave background and cosmic ray regions of the spectrum will not be covered. These are the domains of other satellites.

Beginning with this year's launch of HST and the Gamma Ray Observatory, NASA scientists expect the Great Observatories to be in space for a total of 25 years, with a five-year overlap of simultaneous operation. Second-generation telescopes akin to the Hubble Space Telescope are already in the conceptual stages.

Launch of the Gamma Ray Observatory is now scheduled for the STS-37 space shuttle mission in June. The GRO, which costs $650 million, will detect intermittent and steady sources of gamma rays from some of the most energetic objects in the universe, including colliding galaxies, supernova explosions and neutron stars.

Built to operate for two years but with an expected lifetime of up to a decade, the spacecraft will carry four instruments and will conduct an all-sky survey for about a year before turning to study specific objects.

Following in its footsteps will be the Advanced X-Ray Astrophysics Facility,

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The Ultimate Observatory

The lunar observatory loomed up quickly in the slightly foreshortened landscape. In the bright sunlight, the Moon's surface was an ashen gray, but here in the lunar twilight there were more tans and browns. The rim of the crater that housed the telescope rose up, the top of it cut off by the upper faceplate gasket in his helmet. Clutching an eyepiece in one gloved hand, he slipped the metallic entry card into the door slot with the other. There were so many stars in the coal-dust sky that the patterns of the constellations seen from Earth were beyond recognition. He left Moonboot prints on the dusty floor of the observatory as he made his way over to the telescope...

A nice image, but probably not the way it will be.

Astronomers of the 21st century may indeed spend their nights observing with telescopes on the Moon, but the observers themselves are likely to be back on Earth, staring at a computer screen, munching on a Big Mac, feet propped on a desk. Gone are the days when astronomers left pieces of eyelid on the cold metal of an eyepiece in a frozen dome. Sophisticated electronics systems have changed the state of the art.

Still, the quest for ever more detailed images of faint and distant astronomical objects remains essentially unchanged. And that quest will lead inevitably to the surface of the Moon, which, according to a 1986 NASA-sponsored workshop, is "very possibly the best location within the inner Solar System from which to perform front-line astronomical research."

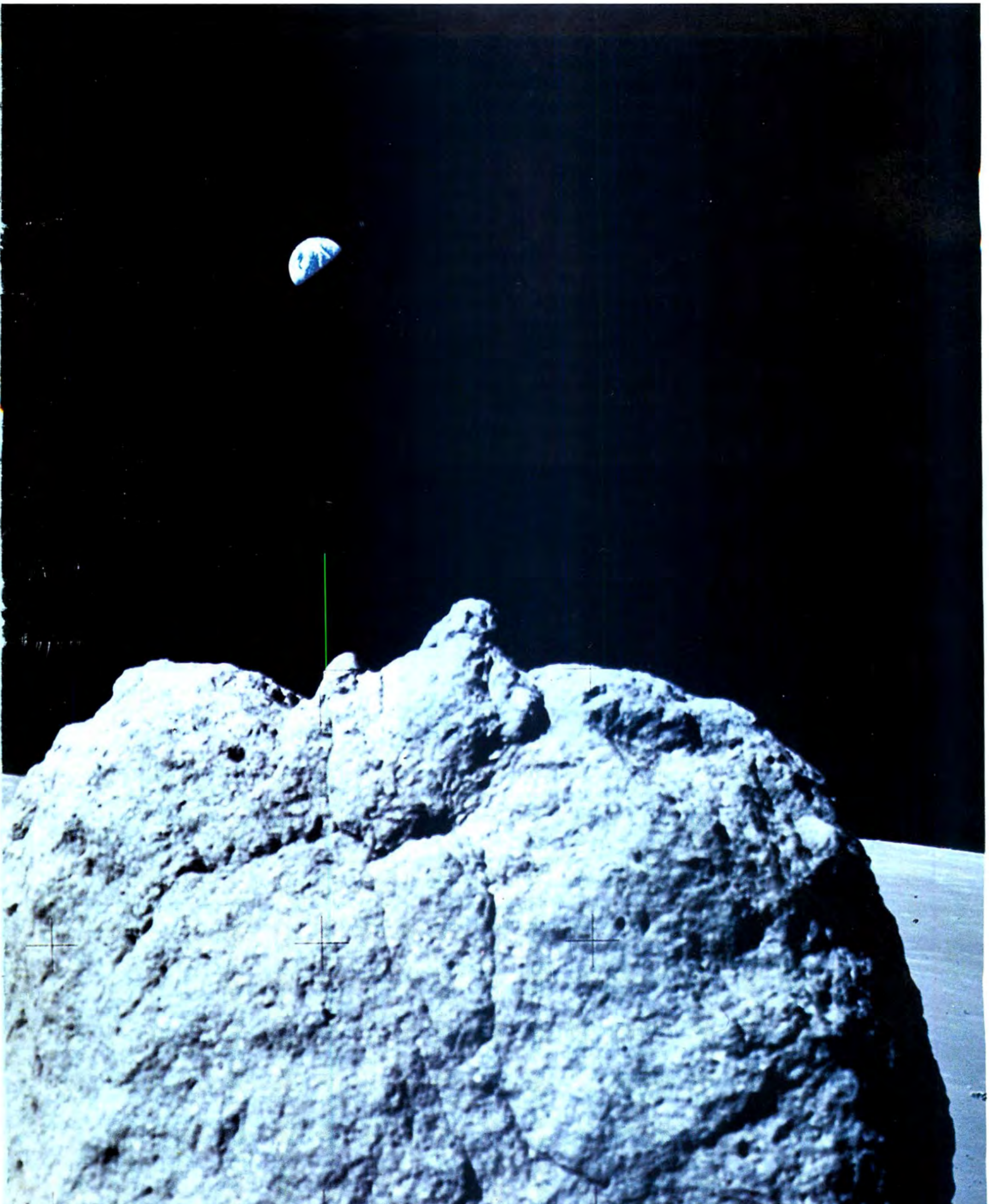
Today that front line is in Earth orbit. The Hubble Space Telescope and NASA's other "Great Observatories" (see page 24) will have a clear new view of the Universe from above the Earth's atmosphere, which blurs fine detail and blocks out most of the infrared, x-ray, gamma ray and other forms of electromagnetic energy raining in from distant objects.

But is that enough? Many astronomers don't think so. Hubble gains resolution—the ability to see fine detail—by virtue of being above the atmosphere, but it is not large by the standards of today's ground-based instruments. If you want to collect more light and see greater detail, you need bigger telescopes. And to image very faint objects, you need longer "integration" times where a detector can soak up photons from a distant source for many hours at a time, uninterrupted.

"Hubble and near-Earth orbit are the only game in town right now," says Harlan Smith of the University of Texas' McDonald University. "But it is a very difficult and very expensive and very frustrating type of place to have to work."

Smith points out that in low orbits the Sun rises every 45 minutes or so, limiting a telescope's view and/or observing time. Furthermore, the Earth fills half the sky, which blocks the view even more. Corrosive atomic oxygen in the thin upper atmosphere presents a

There's one place even better than Earth orbit to put a telescope, and that's the Moon. By Robert M. Powers

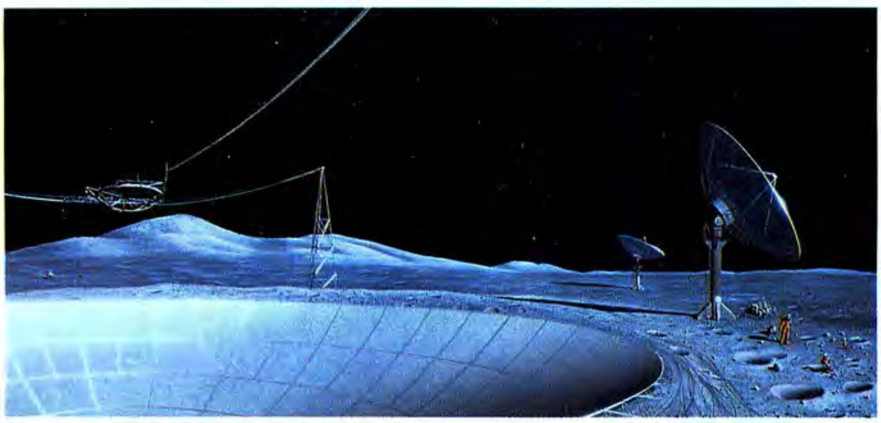


problem, and anything that flakes off or "out-gasses" from the telescope orbits along with it, which could create an artificial "atmosphere." High geosynchronous orbits are better, but the energy required to put a large telescope 22,000 miles above the Earth is not far from that required to send it to the Moon.

"If you're going to truck a telescope *that* far," says Smith, "why not go a little bit farther? If you tried to write out a prescription for an ideal place for an observatory, all the things you might want, you could hardly do better than the Moon."

Astronomy from the Moon is an idea that dates at least to the time when lunar rockets were still drawn with needle-noses. The nearly perfect vacuum offers nearly perfect "seeing" for any telescope, with no atmosphere to blur the image. Even during the lunar day, the sky is dark, free from atmospheric scattering.

Large radio dish antennas would be mounted inside the hollows of lunar craters, while smaller steerable antennas could be built without the heavy support structures necessary on Earth.



EAGLE ENGINEERING

The Moon has lots of real estate for putting up large telescope arrays, and its slow rotation—the lunar "day" and "night" each last two weeks—means that structures would heat and cool slowly, and therefore hold their shape better. Simple sunshades would protect the telescope during the day.

The long lunar nights and days offer another great advantage. An observer on the Moon could watch an object continuously for fourteen days before it set below the horizon. That allows fantastically long exposure times for any telescope. Ground-based observers have to squeeze their observations into a few hours between star-rise and star-set (and pray for no clouds). Hubble is limited to under 40 minutes. But a telescope on the Moon could collect light from dim, distant galaxies literally for days on end.

There are still more advantages for lunar-based astronomy. The Moon is more stable than the Earth seismically, with an average of 500—mostly minor—Moonquakes per year, as opposed to 10,000 on Earth. The lunar far side is shielded from terrestrial radio "noise," which makes it ideal for radio astronomers and SETI (Search For Extraterrestrial Intelligence) observers, who fear that the growing din of radio interference produced on Earth will drown out faint signals from elsewhere in the Universe. The Moon is a good place to detect neutrinos and gravity waves, both of which are about as easy to find on Earth as the Holy Grail.

It's also "luna firma." A telescope on the Moon's solid surface would be easier to anchor and to point than an instrument floating in Earth orbit. It could be built more or less like an ordinary terrestrial telescope, only much lighter and less massive in the Moon's one-sixth gravity. Telescopes on Earth require mass both to resist structural bending and to remain absolutely stable in even slight breezes. On the Moon, there's no wind.

"Actually," says Harlan Smith, "a lunar telescope would be a spidery, spindly thing that looks to our eyes as if it would fall down of its own weight. It would use simple motors, a relatively simple pointing system. It would be, in comparison to any sort of space-based telescope, a *cheap* instrument."

It would be cheap because it can be made light, but also because much of it could eventually be built from lunar materials: aluminum, graphite epoxy, metal matrix composites and castings from lunar rock. Mirrors could even be made on the Moon some day—the raw material for glass is abundant—but the first lunar telescopes probably will be made on Earth and shipped to the Moon.

Where to put telescopes on the Moon has been considered many times over the years. One 1967 study proposed a one-meter telescope (Hubble is two and a half times that size) at the lunar south pole and one in the center of the far side to evaluate the potential of lunar astronomy. The same concept had a twelve-person permanent observatory in the crater Grimaldi, at the eastern edge of the lunar near side, with a batch of radio, optical and x-ray telescopes.

Most older ideas about lunar observatories had the telescopes located close to a permanent base, or vice versa. That is probably not necessary: The Space Telescope will work remotely and might last for fifteen years with only periodic maintenance. A lunar telescope could be just as far away from a Moon base.

According to Smith, by the time a lunar observatory of any size is established, fiber optics technology will be so standard that you could run a cable thousands of kilometers from the observatory to the lunar base—all the communications capability you might ever want, and absolutely reliable. You might have to shield it, but the cable itself would be almost weightless.

What if a telescope on the Moon breaks down? "Breakdowns don't have to be a big problem," says Smith. "I don't see people walking around outdoors all the time on the Moon, doing maintenance. I think robotics will be developed to the point where routine maintenance on the Moon will be performed by robotic devices."

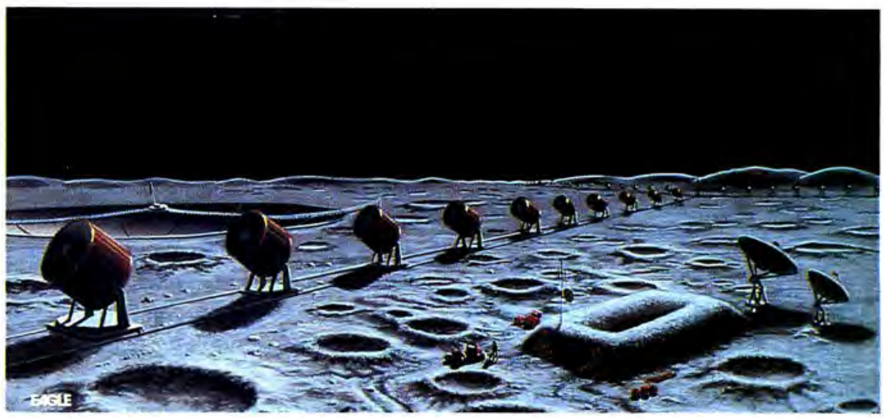
The first lunar expeditions of the next century are likely to begin setting up experiments immediately upon landing, just as the Apollo astronauts did. The first telescope would be followed shortly by prototypes of larger instruments, all tucked into packages that an astronaut—or "selenaut," if you prefer—would haul over the lunar landscape, plunk down, turn on and leave behind to operate automatically.

The key to a lunar observatory is not any one telescope, but many instruments with differing purposes. A lunar-based Schmidt Camera would be the ultimate in mapping the Universe—its inventory of stars and galaxies would make the 18 million-object catalog produced for the Hubble Space Telescope obsolete.

Planetary imaging telescopes on the Moon would be used not for looking at surface features (spacecraft like Galileo and the Mars Observer can do that better) but for monitoring planetary atmospheres on a daily or weekly basis. During the long lunar days, telescopes could use "occulting disks" to block out the Sun from an otherwise black sky—a trick that's difficult to pull off with an orbiting telescope and pointless to do in the bright daylit skies of Earth. This would allow objects near the Sun— including Mercury, Venus and comets in their most active phase—to be observed easily.

Other instruments have been proposed for the early years of humanity's return to the Moon. Radio astronomers are prevented from observing at very low frequencies by the Earth's ionosphere. But a large array of thousands of tiny antenna elements—short wires that could simply be laid out on several square miles of the lunar surface by astronauts driving a rover—would act as a giant low-frequency radio antenna when connected to a central computer. Since astronomers have not yet explored the far end of the radio spectrum, such an experiment could expect to find the unexpected.

Another comparatively simple device would be a fixed telescope that uses the slow rotation of the Moon to scan the sky. This would be nothing more than a primary and secondary mirror, with an electronic sensor like a CCD (charge coupled device)—modern astronomy's replacement for the old-fashioned photographic plate—to do your imaging.



EAGLE ENGINEERING

Lunar arrays patterned after the Very Large Array (VLA) of radio telescopes in New Mexico could observe in wavelengths ranging from radio to x-rays. A linked system such as this, observing in visible light, would be thousands of times more powerful than the best optical telescopes on Earth.

The first lunar observatories will be modest (establishing a base will probably take priority over astronomy at first), and will be competing in performance with ever more advanced Earth-based and space-based instruments.

"But the ultimate goal," says Harlan Smith, "is to get telescopes on the Moon so powerful you couldn't even imagine building them on Earth, nor would you have any reason to do so."

The resolution of a telescope is limited by its size, and size is limited by the effects of gravity (witness the fate of the Green Bank radio telescope in West Virginia, which collapsed under its own weight last

year). In the quiet of the lunar far side, huge radio telescopes standing steady in the one-sixth gravity of the Moon will listen in on the Universe with unprecedented sensitivity. Still larger dishes could be placed inside lunar craters. The giant Arecibo radio telescope in Puerto Rico is supported by the natural contours of a bowl-shaped valley. On the Moon, bowl-shaped craters are everywhere.

But radio astronomers on Earth have found another way to beat the size problem by using "aperture synthesis," whereby an array of many individual telescopes is linked together electronically. The equivalent resolving power is the same as if there were one large telescope as wide as the separation between the elements.

The most powerful synthetic aperture instrument on Earth is the Very Large Array—27 radio telescopes strung out in the desert near Socorro, New Mexico. There are plans to extend the "baseline" even further by linking together radio dishes stretching from Hawaii to Puerto Rico. But a far greater separation could be achieved if one of the elements of the array were placed on the Moon. Such an instrument would have 10,000 times the resolution of the VLA, and would give radio astronomers a powerful new tool for exploring, among other things, the energetic centers of galaxies, including our own Milky Way.

The implications of micro-arc second resolution are difficult to fathom at first. It means, in principle, that you could see *continents* on Earth-sized planets around nearby stars. Or features on Pluto as small as an office building.

VLA-type arrays are envisioned for other wavelengths, as well. Perhaps the ultimate in optical astronomy would be an interferometry array that used the same principles to observe in visible light. Optical interferometry is extremely difficult to do on Earth, due to the distorting effects of the atmosphere. And the precise alignments required between individual elements make space-based arrays difficult, if not impossible.

But the Moon's surface offers a stable anchor for aligning telescopes, lots of room to spread them out, and no atmosphere. A lunar optical array modeled after the VLA could have 27 mirrors nearly four feet in diameter, arranged in a Y shape. Each arm of the array would be some 3.7 miles long. This kind of rig, which would be unique to the Moon, would have the equivalent resolution of a fantastic telescope more than *six miles* in diameter.

The whole thing would "nest" easily for transport. Shipping weight from Earth: about seven tons for all 27 telescopes, roughly equivalent to hauling one module to the Moonbase. As the lunar base grew in size and capability, the array could be extended. Stretching across the lunar surface, probably on the floor of a flat crater, an extended optical array could (if the curvature of the lunar horizon doesn't pose too great a problem) provide a baseline of nearly 40 miles.

Building such a beast on the Moon would be no easy task, even given an advanced lunar base. But the scientific reward would be enormous. A four-inch backyard reflector has a resolution of about one arc second (the sky is divided into 360 degrees of arc, which is further subdivided into minutes and seconds). That's also about as steady as the Earth's air gets, except on special occasions. But a large optical array on the Moon could eventually get resolutions on the order of one *millionth* of an arc second.

"I've spent a lot of time," says Harlan Smith, "thinking about what micro-arc second resolution means. It means if you had one of these telescopes in San Francisco, you could study single-celled creatures in New York!"

It means that astronomers could track star-spots, flares and other features on the surface of virtually any star, whereas now they see this kind of detail only on our own Sun. Observations of the active regions around suspected black holes would be astounding. High-resolution radio observations have measured velocities in the centers of quasars that *appear* to surpass the speed of light. The current belief is that this is an optical illusion caused by the orientation of the objects relative to our line of sight, but visual observations in the micro-arc second range could help find out.

The implications of micro-arc second resolution are difficult to fathom at first. It means, in principle, that you could see *continents* on Earth-sized planets around nearby stars, out to a distance of 10 or 20 light years. Lunar-based astronomy could in fact be the key to our study of "extrasolar planets," which are now only thought to exist.

The optical interferometry array would probably not be used much to observe in

continued on page 59

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AN ORBITING CONSTRUCTION SITE

By the turn of the century, astronauts will have a permanent home in orbit. But first they have to build it.

Most of the time it isn't as strange, as mesmerizing, as downright terrifying as others might think. You are concentrating...deeply. Up here at the planet's boundary, where the cost of time and materials is...well, astronomical, mistakes are not appreciated. So you pay attention. Your hands, fighting the pressure in your insulated gloves, feel as though they've done a hundred finger-tip push-ups. Hauling your 400-pound space suit around, even in weightlessness, you work up sweat by the quart. It's all very reminiscent of the hours you and your fellow astronauts practiced in neutral buoyancy tanks at the Johnson Space Center.

Building a space station is not easy. Nevertheless, being human, you occasionally lean out, away from the work at hand, and look straight down. That's when it hits you: you aren't in any water-filled tank, but 210 miles above the Earth. Below, in the black night, a hundred thunderstorms burst across whole hemispheres like so many planetary fireflies. The serene darkness of the Himalayas is slashed by snowy peaks that glisten in the light from the moon over your shoulder. Even in its strangest dreams, the human brain did not evolve to deal with these experiences. This is not sprinting across the savannah in search of dinner, nor falling apelike from tree to tree.

Here among the unwinking stars, it's difficult to fathom that anything engineered by humans could, or should, exist. Yet there it is, Freedom — the international space station. Half a million pounds of gleaming graphite epoxy struts and beams, strung together in a "transverse boom" 508 feet long. Clinging crosswise to its mid-section are four cylindrical modules — rooms for living and working in space. Along its bridgework rest instruments for studying the Earth and the stars. At each end hang four solar panels, which provide the station with its electrical power and give it the look of a giant insect not quite properly equipped for flight.

Yet, at last, it does fly....

By Chip Walter

Or at least, come the turn of the millennium, a lot of people are hoping it will.

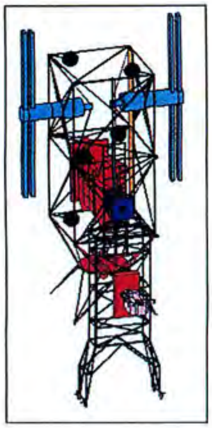
Whatever the controversies in these days of unrelenting social problems and Gramm-Rudman budget slashing, the international space station Freedom is arguably the most dreamed about, most discussed and most difficult piece of engineering since the Chinese pooled the toil of millions to construct the Great Wall. If NASA's present schedule holds, the last bolt will be tightened in August 1999, and a mighty fusillade of champagne corks will pop around the world. By then, 29 teams of astronauts, two revolutionary robots and uncounted thousands of engineers, scientists, bureaucrats and politicians in 17 countries will have sweated to make it a reality. Meanwhile, the rest of us Earthbound taxpayers will have watched the station grow from a tiny point of light to one of the brightest objects in the evening sky.

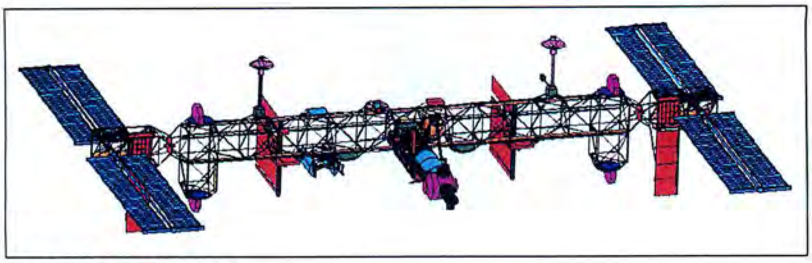
But getting to that day won't be easy — the space station demands construction materials and assembly techniques that would turn even the most adept earthbound architect's hair snow white in anticipation.

"This is," as Space Station Operations Deputy Director James Sisson succinctly puts it, "a very complicated business. And it's the first time we've done it."

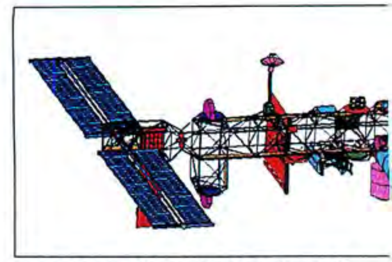
The thing to keep in mind about Freedom is its size. It isn't much by Earth standards — fifty stories — but as spacecraft go, it's a journey into the twilight zone. Nothing so immense has ever been placed in orbit, let alone constructed there. Until now, large payloads have gone up whole on the backs of big boosters after being assembled and checked out in "clean rooms" on the ground. Even the Soviet Mir space station — which, like Freedom, is designed for expansion — rode into orbit in one piece onboard a muscle-bound Proton rocket, no assembly required.

PAUL DIMARE





MAN TENDED CAPABILITY



PERMANENTLY MANNED CAPABILITY

FIRST ELEMENT LAUNCH

But when space engineers plan to build a structure that approaches the size of two football fields, all the old rules change.

"We're going to have to launch this thing in pieces and put it together in space," explains Sisson. "Every time you launch something and put it in orbit you've got a new spacecraft. It has to function after it's left behind, and it's got to be stable. So what we're really talking about is launching in excess of 20 spacecraft."

And not just any spacecraft. The building blocks of Freedom must unfold from the back of the shuttle with the elegance of a butterfly from its cocoon, then work together flawlessly as each new piece arrives. Dave Walker, a shuttle astronaut and Freedom's special manager for assembly, says "It's like building a ship piece by piece while it's floating, going away for 45 to 90 days, then coming back to the work site to find it still floating where you left it — hopefully," he adds, "with no major leaks."

If the station *doesn't* stay afloat while still under construction, some $30 billion in hardware, engineering and imagination could tumble out of control in an unfortunate illustration of Newton's law of gravity. So NASA and industry engineers understandably are burning up a lot of brain cells and computer chips to figure out the complicated task of assembly. Computer simulations have built and rebuilt the station in more shapes and sizes than a five year-old with a box full of Tinkertoys could conceive.

"You have to plan how you're going to break the station up into pieces," says Bill Bastedo, Freedom's systems analysis chief. "Then you have to think about the order in which you want to take those pieces up, and make certain everything fits into the shuttle correctly — not a trivial issue. Finally, you have to figure out whether you can actually put it all together. Is there enough [spacewalking] time available on that flight? Can the robots help? Can we actually reach something we need to reach so we can get it into place when we have to?"

Those are the problems. What are the solutions? The current plan calls for the station to be assembled, manned and supplied over a three-and-a-half-year period between March 1995 and August 1999. The shuttle will be the booster of choice for all three tasks, with 29 flights in all. Right now there are no plans for new heavy-lift launch vehicles to help out, which makes shuttle detractors nervous — all of Freedom's eggs are in one basket.

The station will be built by 40 teams of two astronauts each, who will work, for the most part, tethered to the station or the shuttle. There will be no place for fancy tools or complicated (and therefore dangerous) assembly techniques. For safety reasons, time outside the shuttle will be limited, with as much as half set aside for unforeseen contingencies.

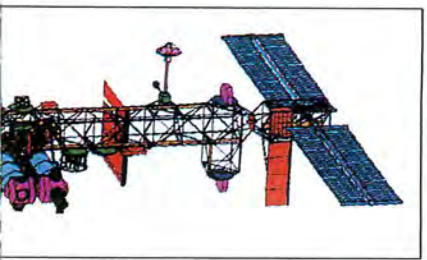
Designed to fit snugly in the shuttle's cargo bay, each piece of the station will be a marvel of packaging. Out of the bus-sized confines of the bay, construction crew after construction crew will unfold the station's trusswork and solar panels, robots and living modules, and the cables and supports to keep it all together.

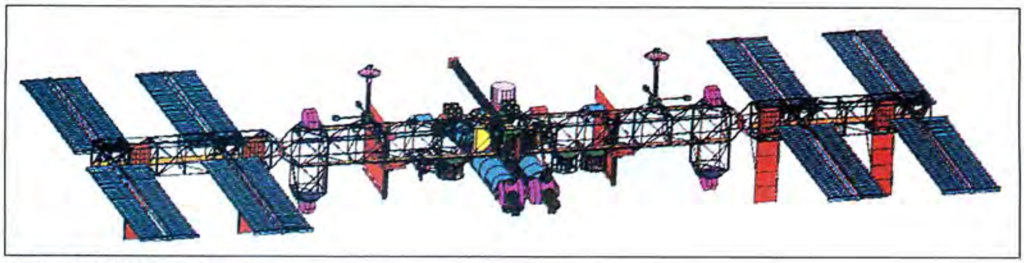
To cut down on the time astronauts will need to work in space, two highly sophisticated robots are being developed. One, built by Canada and based on the shuttle's manipulator arm, is called the Mobile Servicing System (MSS). The smaller Flight Telerobotic Servicer (FTS, in NASA lingo) is being developed in the United States. No other project has required such intimate relationships between man and machine. And even if both work flawlessly, it's going to be a tough job.

When the time comes to launch the first piece of the station in the early spring of 1995, fingernails will be in short supply at NASA technical centers around the country. Inside the space shuttle will be a crew of seven, including two assembly teams of two astronauts each. Only one team at a time will work on the assembly, to reduce fatigue and time spent outside.

After three full days in orbit, the first team of astronaut hardhats will double-check their procedures for the last time and prepare to leave the shuttle. As the airlock opens, the Earth below will spin silent and serene — no evidence of turmoil, war, famine or disaster. The view will be awesome, but...there will be this *job* to do.

When flight number one arrives, there will be no footers or foundations, no skyhook from which to hang the station. The astronauts will construct the initial section of Freedom's spine right out of the shuttle bay as they stand on a swinging platform that allows them to move around a pallet holding the building blocks of the truss. These sections will be cube shaped, about 16 feet on a side, assembled from simple struts and joints that resemble giant Tinkertoys. Astronauts will slip each strut into a ball-shaped joint, then snap it into place with a quick turn of the wrist. No fuss, no muss.





ASSEMBLY COMPLETE

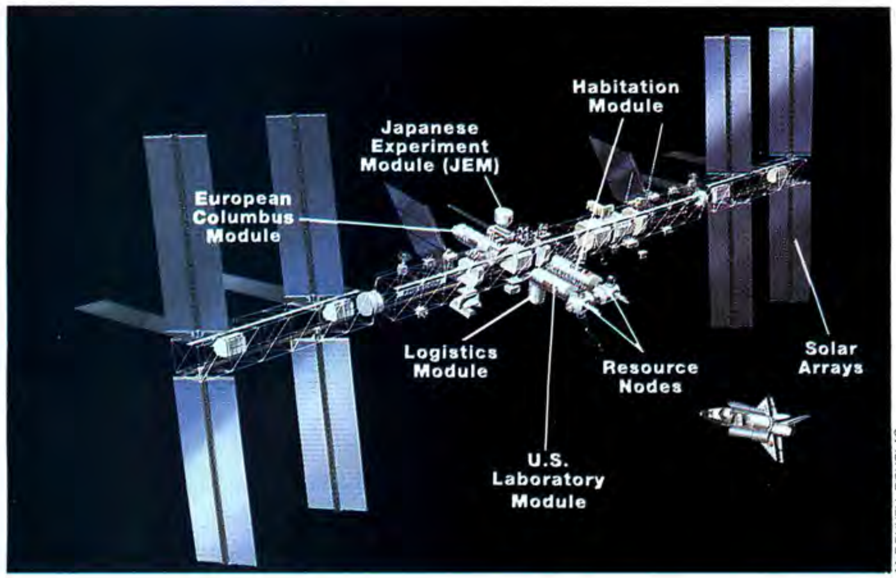
When one cube is finished, the spring-loaded pallet will push it upward. Then, by slipping new struts into the ball joints of the previous cube, the next one can be snapped into shape and sprung upward to make room for another. As all of this is being done, power and computer cables, water and gas lines will be unraveled and attached to the truss as it is built.

On the first flight, astronauts will work a total of about 24 hours — six hours each — to run 30 feet of truss from the back end of the shuttle bay. The workload on any flight will never exceed 36 hours, except in emergencies.

In order to keep the embryonic station stable in orbit, the astronauts will fasten magnetic dampers to the trusswork that push and pull against the Earth's magnetic field. They also will attach, but not unfurl, four solar array panels, and will add a work platform to be used by construction crews on later flights. All of these jobs may be aided by the FTS robot, which would be operated by remote control, first from the shuttle, then later from the station itself.

"We'll probably try the FTS out on the first flight to see how it's working," says Bastedo. "By the time the second flight arrives, we expect to be using it regularly to help with the assembly." Exactly *how* the robot will be used is still under discussion.

On flight two the starboard solar arrays will be extended, and power will begin flowing to rudimentary communications and propulsion systems. The pallet used to push the truss out of the bay on the first flight now will run along the top of the station's spine like a high-tech coal car. This little trolley will enable subsequent assembly teams to roll along the exterior of the station, extend the truss and play out the remaining cable and utility lines ahead of them as they go along.



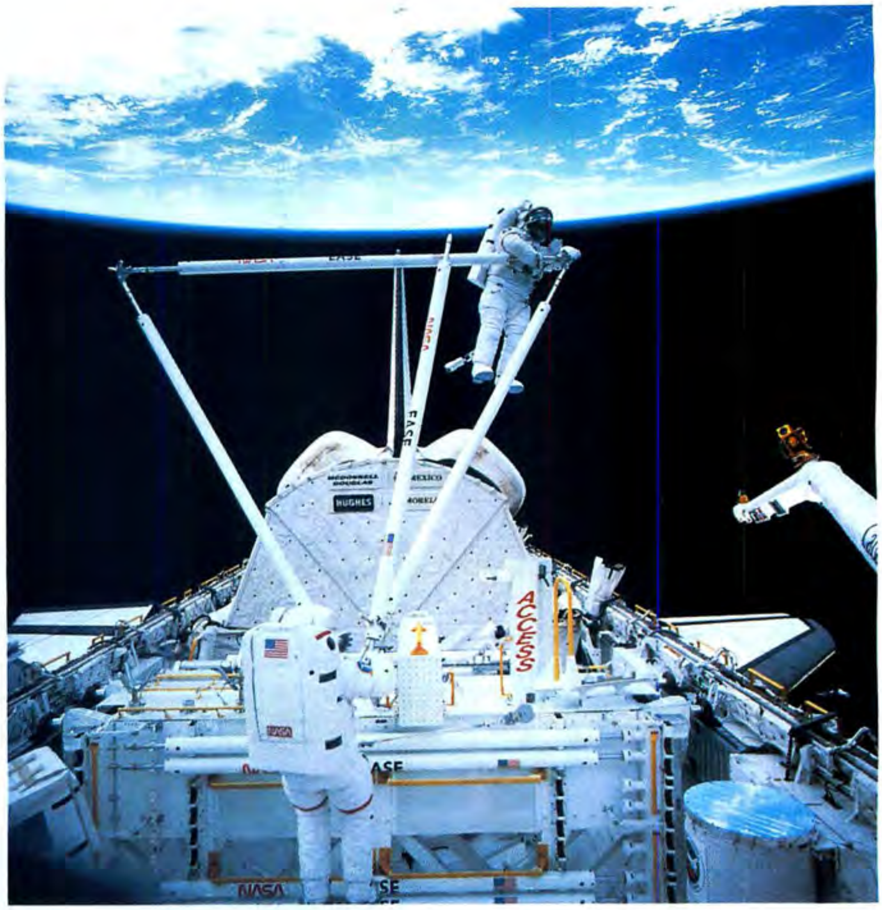
McDONNELL DOUGLAS

See how it grows: The first section of Freedom is scheduled for launch in 1995 (opposite page). The arrival of the U.S. lab module in 1996 will begin "man-tended" operations, but the station won't be ready for permanent occupancy until 1997, when the crew quarters are installed. By August 1999, the fully assembled Freedom (above) will have eight people onboard.

Over the next year, four more flights will lay the foundations of the station. Every two or three months, the skies over Cape Canaveral will thunder to the sound of shuttles packed with tanks of liquid nitrogen and oxygen (portable atmosphere), a docking mechanism and propulsion pallets to boost the station periodically so its orbit doesn't decay. Most importantly, the astronaut assembly crews will continue to add more building blocks to the structural backbone until it grows from 30 to 500 feet.

Finally, on June 15, 1996, the shuttle arrives with Freedom's first "room" — the U.S. laboratory module, a 14 by 42- foot cylinder that fits snugly in the shuttle cargo bay. At that point the station will attain, in NASA's bottomless compendium

McDONNELL DOUGLAS



of acronyms, MTC, or Man-Tended Capability. That means astronauts will be able to work onboard the station but not live there, attending briefly to experiments while the job of assembly continues around them.

Amenities will be spartan, with no bunks as yet. All sleeping and eating will be done in the familiar, if cramped, confines of the shuttle. But astronauts will be able to work onboard the station in their shirt sleeves, and the commute won't be long — no more than a float through the airlock linking the shuttle to Freedom. When the shuttle leaves, low-gravity experiments dealing with everything from hydroponics to materials processing will be left behind to "cook" for two or three months, unattended and undisturbed, until the next flight arrives.

With Man-Tended Capability, the United States will at last have a place to perform long-term experiments in orbit — something the Soviets have had for years in the Mir space station. Now the real guts of the station begin to arrive. On flight nine, with the help of the FTS and its fellow robot, the Canadian Mobile Servicing System — which by this time is shuttling along the completed central truss — astronauts will attach two of the station's resource nodes. These are small pressurized cylinders, 22 by 15 feet, that act as command and control centers for the station's propulsion, tracking and guidance systems, and also as the passageways between the four large modules.

Altogether there will be four of these nodes, one at each end of the two U.S. modules. Two of the four will be outfitted with a "cupola" that protrudes into space — one facing Earth, the other facing the rest of the universe. Crewmembers inside the cupola will have an eight-window, 360-degree view — the most magnificent the station has to offer. From here they will operate the station's robots and communicate with astronauts working outside.

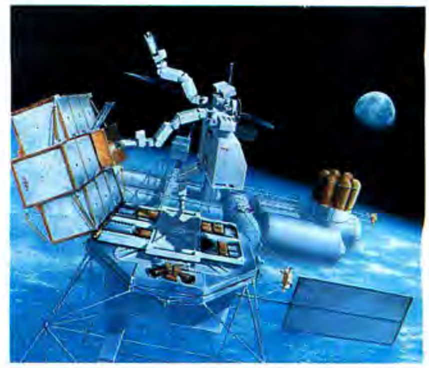
From the beginning, the driving idea behind the space station was that it be a place beyond Earth where people could live and work permanently. That promise will at last be fulfilled on January 31, 1997, when the shuttle shows up with Freedom's living quarters. The "habitation module" will be more like a trailer than a luxury condominium, but it will be opulent compared with the Skylab of the 1970s or even Mir — a kind of space-age locker room/bunkhouse complete with galley, medical facilities and exercise area for eight international crew members.

Although the "hab" module contains extremely complex equipment, it will be relatively easy to install. The shuttle will dock, back end facing Earth, bay doors open, the shuttle's arm poised to remove the module. An astronaut will enter the station through an airlock and float down to the forward resource node's cupola. From there, he or she will guide Freedom's Mobile Servicing System along the truss to the docking area, where its 58-foot arm will take the module from the shuttle arm like a halfback takes a handoff. The MSS will then hoist the module into position and hold it there — all the time circling Earth at 17,000 miles per hour — while two astronauts bolt it into place.

Meanwhile, inside the station, the crew will unload canisters filled with whatever hardware and supplies couldn't be built into the module on Earth. Bobbing around the innards of the module, astronaut specialists will hook up and check out computer, power, water and gas lines while a telerobotic operator manipulates the FTS and checks connections outside the station.

The next two flights deliver more supplies and the station's last resource node. Then, in the summer of 1997, flight number 13 ferries up the first permanent crew — four specialists who will live and work

Former astronaut Pete Conrad (now an executive with space station contractor McDonnell Douglas) tries his hand at building a "space station" in an underwater training tank (opposite page, left). Shuttle astronauts practiced construction tasks in orbit on mission 61-B in 1985. Spacewalking astronauts will test another piece of space station hardware—a trolley for moving construction crews along Freedom's trusswork—on the STS-37 mission in June. Right: The FTS may lend a robotic hand in the job of assembly, and will eventually help in servicing the station.



onboard the station for the next 90 days. After all the years of dreaming and debate, after all the setbacks, technical gymnastics and budgetary blood baths, Wernher von Braun's vision of a "new companion in the skies" will become reality. At last, the United States will have its space station.

But what about the international partners who are footing nearly a third of Freedom's total bill? Aside from Canada's Mobile Servicing System, it's an all-American show until mid-1997. Since the United States is putting up the lion's share of technology and hardware for the space station — and since it owns the only spacecraft that can launch it — the plan has always called for taking care of U.S. needs first. Nevertheless, the project will begin showing its true international colors in February 1998, when the first section of the Japanese Experiment Module (JEM) arrives.

Ever so gently, the shuttle will float toward the station, crown first, its pilot punching a thruster or two to position the spacecraft just so. By now, docking to the station will seem almost routine. Once more, robots and astronauts will work together to pluck the module out of the cargo bay and place it at the end of the habitation module.

JEM is a fitting acronym for Japan's contribution to the station. It *is* a gem — a compact, two-person laboratory with its own robotic arm capable of performing experiments on a 30-foot deck outside the module. The Japanese module also sports a kind of small "attic" — a detachable cylinder to be filled with supplies and specimens for low-gravity experiments, which

continued on page 61

A SPACE STATION TOOLBOX

Extravehicular Mobility Units (EMU's): Slightly advanced versions of the Manned Maneuvering Units that now allow shuttle astronauts to motor around in space without being connected to a tether. The EMU's won't arrive until flight 12 — long after the station's truss is assembled. Tethering is safer. The plan is to use them mostly for maintenance work.

Flight Telerobotic Servicer (FTS): Like the father of a young son, NASA has high hopes for the FTS. The idea is for the robot to aid the construction and maintenance of the station and thereby cut the risky business of astronaut extravehicular activity. The FTS is not the sort of science fiction robot that can crack wise and go off in search of its master. What it *will* be is an elaborate extension of the human body, able to take on dangerous and intricate jobs outside the station while an astronaut operates it from inside the shuttle or the station, or even from Earth. The FTS will be six feet tall, with camera eyes and three limbs sporting manipulators nearly as sensitive as human fingers. Eventually, its builders hope the robot will be able to handle complex maintenance jobs on its own.

Mobile Servicing System (MSS): This contraption consists of two robots and a trolley. The transit system is a NASA-designed pallet that will shuttle along the length of the station's spine to move the arm wherever it needs to go. The two Canadian robots are a significant contribution to the station — in fact, the MSS is central to the station's assembly. If it breaks, construction comes to a halt. For that reason it will be sturdy enough to handle 110 tons — three times the capacity of the shuttle's Canadarm. It also will be smart. At the end of its 58-foot arm will be a highly sensitive SPDM (Special Purpose Dexterous Manipulator). This separate, smaller robot will use its two six- foot arms for delicate jobs like repairing electrical circuits and fuel lines. The MSS also will be tele-operated.

"Don't Change That Station!"

How NASA managers tried to beat the budget-cutters at their own game, and wound up offending just about everyone in the process.

By Lori Keesey

By summer of last year, NASA's top brass had begun to face facts. Congress wasn't buying the "all or nothing" arguments used by previous agency officials to finagle cash for the financially strapped space station Freedom program. So the administrators did what had been considered unthinkable until then: They quietly ordered an exhaustive descoping of the multi- billion-dollar project.

And so began, one day after the July 4th holiday, a series of workshop meetings that came to be known as "Scrub '89." Although Congress would eventually appropriate nearly $1.8 billion for Freedom in 1990—more than NASA officials had anticipated at the time—repercussions of that three-week exercise still can be felt today. As a chapter in the space station's troubled history, it neatly illustrates the difficulty of steering a large, expensive, multi-year, international project through the American political system. It sparked contention and misunderstanding among lawmakers and NASA's international partners. And even now, no one can guarantee that it won't happen again.

But all that lay in the future last summer, when the space station seemed headed for real crisis. The program's top three managers had just quit. The House appropriations committee, which sets NASA's budget in the House, was recommending a $400 million cut in Freedom's 1990 funding request of $2.05 billion. And committee members were warning that an additional $600 million would probably be slashed the following year.

That was the situation facing William Lenoir, a former astronaut turned Associate Administrator for Space Station, and Space Station Director Richard Kohrs, shortly after they accepted their new jobs heading the perennially beleaguered Freedom project.

With the funding outlook apparently out of step with NASA plans, it was time to admit that either the timetable would have to slip—again—or the station itself would have to be down-scaled. The question was, who would lead the "scrub" effort, and where would it be held?

Ray Hook, Director of Space Programs at the agency's Langley Research Center, was the logical choice. He was no stranger to the Freedom project. In 1986, the 30-year NASA veteran had won the agency's coveted Outstanding Leadership Medal for managing a 35-member task team that recommended sweeping changes in the program's design and assembly. He also had headed Langley's space station project office. He knew the program and the people.

So Langley ended up hosting the event, partly because it was Hook's home, and

PETE BASTIANSEN


NASA'S MANNED SPACE STATION
USA
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partly because it had enough secretaries and computers to support the task force. NASA's oldest field center offered other benefits, as well. It was neutral, meaning that it wasn't one of the four centers designated by the agency as prime work sites for the Freedom project. It also was far away from Washington, nestled 100 miles south in Virginia's Tidewater area.

There would be no interruptions. Lenoir had given Hook's 16-member "tiger team" of astronauts, senior managers and key project officials specific guidelines. He didn't want recommendations. He wanted options on how NASA could cut some $1 billion in station funding in 1990 and 1991, and still be ready to begin building Freedom in orbit in March 1995.

"I felt we needed to hold the first launch date so we could show progress," Kohrs said. Indeed, after five years the program had little to show for itself, and meeting an important deadline would go a long way toward soothing congressional anxieties.

Hook's team was told to maintain international agreements to the "maximum extent possible," to allow for eventual growth back to the original station design, and to support the community of users waiting to fly experiments on the station. Those were the marching orders.

It was an intense three weeks, characterized by 12-hour days, seven days a week. The task force members, chosen because of their key roles in the program, met Tuesday through Thursday of each week at Langley, then briefed Lenoir and Kohrs on Friday. Saturday, Sunday and Monday were spent at other NASA centers, working the numbers and new configurations with contractors and agency personnel. The fax machines and telephones never stopped.

"It was like disassembling your automobile," said Bob Rhome, who represented NASA's Space Science Office. "We were told to identify a series of elements that could be disconnected." It took work, but by all accounts the team members were able to cast aside their biases for the good of the program.

"If we were going to bleed, we thought *we'd* rather do the bleeding," said Ron Browning, a project manager at Goddard Space Flight Center.

Lenoir had asked for options that reduced station funding by $400 million or more—the expected amount of budgetary shortfall. "Quite honestly, we didn't make it," said Hook. But the proposed cuts were painful, nonetheless. "Truthfully, we cut it too much," admitted Hook. "We were at the point of non-viability, and we had some real uncertainties about what we'd done."

What the Langley group *had* done was to reduce the size of the station's crew from eight people to four. It slashed the amount of onboard electrical power by half, from 75 kilowatts to 37.5. It decided to scrap a new, improved space suit. Oxygen would be delivered to the station instead of generated onboard, which meant more shuttle flights. The team opted for a greatly simplified propulsion system that used less electricity, but drove up operations costs, and—according to critics—polluted the vacuum environment outside the station.

> "Here we were, trying to split a chicken into 55 parts." Meanwhile, in Washington, President Bush was talking about manned missions to the Moon and Mars. "We were saying, 'What's wrong with this picture?'"

There were still more casualties: The group deleted the onboard washer, dryer and dishwasher, and decided that the shuttle would control docking operations, rather than the station. It recommended fewer "attached payloads"—science instruments mounted to Freedom's exterior. It reduced communications and tracking. It scaled back data management systems. It changed the power distribution system. And as defined by the Langley team, "permanent manned capability"—one of the station's main selling points—didn't necessarily mean "forever manned." Money could be saved down the line by occasionally leaving the station unoccupied.

By the time it closed shop in late July, the Langley team had planned the station's assembly schedule to 1997, when the second U.S. module would be in place and Freedom could be permanently manned. The group never examined possibilities beyond that point. In fact, NASA didn't finalize the assembly sequence until after the Langley group had disbanded and discussions had begun with international partners and other program officials. This would later prove disastrous from a public relations standpoint.

To one workshop participant, the whole exercise was a terrible contradiction: "Here we were sitting down in Langley, trying to split a chicken into 55 parts." Meanwhile, in Washington, President Bush, flanked by his Vice President, NASA Administrator Richard Truly and the Apollo 11 astronauts, was talking about manned missions to the Moon and Mars. "We were saying, 'What's wrong with this picture?' We're not sure we can afford a $26 billion space station," let alone an ambitious Moon–Mars initiative.

"It was like two trains passing," the official added. One, filled with fresh, young recruits, was just heading out. The other was returning from the front lines.

And within a few days, all hell would break loose.

Officials at the European Space Agency (ESA) first heard about the scrub exercise through the industry rumor mill. By mid-July its Washington representatives were clamoring for a briefing. They got one, but details had been omitted from the agenda. When formal briefings began a few weeks later, they and their Canadian and Japanese colleagues learned why.

The 50% power cut left just 18 kilowatts of electricity for running onboard experiments, which would reduce the station's usefulness as an orbiting laboratory. The new assembly sequence didn't include a firm launch date for the European and Japanese modules. It also appeared that international partners would have to bear increased operations costs because of changes in the propulsion and environmental control systems. ESA's Man-Tended Free-Flyer—a small, automated laboratory flying in tandem with the main station—would need servicing, but NASA didn't make provisions for that.

More unsettling was the fact that NASA hadn't included its partners in the Langley exercise, even as observers. That constituted a clear violation of international agreements, which stipulated that

NASA would consult the partners about any potential changes, an ESA official said. "What made it worse," he added, "was that we didn't have any information."

As ill feelings reverberated across the Atlantic, Canada, which historically enjoyed a "good relationship" with the space agency and had agreed to build Freedom's advanced robot arm, also was having trouble swallowing NASA's latest bitter dose.

"It was an incredible leap of faith for Canada to get involved" in space station Freedom in the first place, explained a Canadian official. America's problems pale in comparison with Canada's, whose deficit equals $250 billion in U.S. dollars. Now, said the official, "all kinds of rejiggering was going on to meet U.S. budget problems."

By early September, ESA Space Station Director Frederick Engstrom had come up with a proposal of his own—that NASA launch the international modules *ahead of* the U.S. laboratory, which would be deferred at least until 1997. In the meantime, the United States could use Japanese and European facilities. Engstrom argued that his proposal produced the same "upfront" savings as the Langley plan. NASA didn't buy it.

"The beautiful thing is, it would have worked," said one NASA official who disagreed with the agency's position. The European offer would have saved money and kept the internationals happy, but it fell victim to national pride.

If NASA thought it had problems with its partners, things weren't much better on Capitol Hill. Some lawmakers perceived the Langley exercise as yet another example of out-of-control NASA programming and lack of vision. In five years, Freedom had undergone 11 major reviews as well as continual budget and schedule adjustments.

"What people don't realize is that when you nickel and dime a program, you're going to drive up costs and stretch out the schedule," said one congressional aide. "The blame can be shared equally. Unfortunately, some of the critics don't want to share the blame."

The House Science Committee, which authorizes space agency spending but doesn't control how much money is actually appropriated, was especially unhappy. Members of the committee, led by chairman Robert Roe, a Democrat from New Jersey, complained that NASA hadn't kept them informed of the proposed changes.

One NASA official saw other reasons for their consternation: "We're caught up in a battle between the authorizing and the appropriations committees." Some members of the science committee thought NASA should have played hardball with the budget panel when it threatened cuts to the station. But instead of picking a fight with another congressional committee, they vented their anger on the victim.

Others in Congress worried that the Langley cuts would become a "self-fulfilling prophecy." Unlike former NASA Administrator James Fletcher, who had told Congress he would rather cancel the station than accept a penny less than the full requested amount, Truly had begun the scrub exercise before Congress even finished reviewing NASA's budget.

"When you nickel and dime a program, you're going to drive up costs and stretch out the schedule," said one congressional aide. "The blame can be shared equally. Unfortunately, some of the critics don't want to share the blame."

In early September, key Appropriations Committee members confronted Truly with information they heard "through the grapevine." Reps. Bob Traxler (D-Mich.) and Bill Green (R-N.Y.) said Truly had ordered the Langley scrub because of additional funding shortfalls that NASA had been keeping quiet. Even if the panel had granted Freedom's full request of $2.05 billion in 1990, the Congressmen charged, NASA couldn't go ahead with the project as planned without significant delays or changes to the station. Agency officials countered by claiming that the extra costs were for "nice-to-have," but non-essential, items suggested by the field centers, which would have been scrubbed out of the budget anyway.

Still, it was clear that NASA was having difficulty keeping control of the program. "After more than $2 billion in appropriations, three major descopings and five associate administrators, the space station program still appears to be 'at sea,'" wrote Traxler and Green.

In hindsight, agency officials concede they could have done a better job explaining the Langley review, but denied allegations that they had purposely tried to keep it under wraps. Besides, said NASA spokesman Mark Hess, the proposed cuts were not the final word, but more of a "first whack."

Still, some lawmakers complained that they were now unsure exactly what the space station looked like. At a hearing in late October, Norman Mineta, a California Democrat on the House Science Committee, called the project "a bait and switch" operation. "I get the feeling that we're hooked onto something, but what we're getting is less capacity and a longer time in getting it."

By the time NASA finished reviewing the proposed Langley changes, which Lenoir called unacceptable, the program did indeed look different. The new schedule called for assembly of the station to be completed in August 1999—almost a year and a half behind schedule. The original crew of eight would be retained, and the station would generate its own oxygen after all. Electrical power would remain at 75.5 kilowatts, although experimenters might now be allotted as little as 30 kilowatts, instead of the promised 45, due to greater power demands by the station itself.

Construction was still set to begin in 1995, as Lenoir and Kohrs had wanted, but all other milestones slipped by six months or more, including the launch of the Japanese and European lab modules. Some of the program's prized systems—an advanced space suit, for example—would still have to fight their way back into the "baseline," but most of the items cut by the Langley team were reinstated. And even though the final appropriation for Freedom fell short of the $1.85 billion Lenoir said he needed in fiscal year 1990, NASA claimed that program reserves would cover the difference.

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Reviews

For All Mankind ■ *A Film by Al Reinert*

By Jerome Richard

When *Texas Monthly* magazine asked Al Reinert to write an article commemorating the tenth anniversary of the first Moon landing in 1979, it was just another assignment. After he talked to some of the Apollo astronauts and watched the footage they'd brought back from the Moon, it became a mission. Reinert's article, "Moonstruck," conveyed the sense of awe he felt at the lunar landings, but he wanted people to share in the experience itself. So he set out to make *For All Mankind.*

Reinart pieced his film together by using the extensive footage taken by the astronauts during their lunar voyages, little of which has been widely seen by the public. That turned out to be something of a technical challenge; NASA had six million feet of 16-millimeter film, but none of it could be removed from the Johnson Space Center, and Reinert had to transfer NASA's prints frame by frame onto 35-millimeter stock for commercial use. He also gathered clips from the television transmissions broadcast by the Apollo crews back to Earth. Onboard views are interspersed with NASA's own documentary shots of the action in mission control.

The finished film combines footage from the eleven Apollo flights (including six Moon landings, two lunar orbit missions, and one abort) and melds them into a single composite voyage. From the bone-rattling launch to splashdown in the Pacific, you see what the astronauts saw. Even the harrowing explosion of an oxygen tank, 200,000 miles from Earth, aboard Apollo 13 is recorded. That mission had to turn back, but the viewer carries on to land on the Moon's surface.

As dazzling as the images from space are, the narration—culled from 80 hours of interviews with a number of Apollo astronauts—gives the film its striking personal quality. We hear the voice of one astronauat who describes looking down from Earth orbit and seeing the flickering campfires of nomads in the African desert. He says they seemed more alien to him than the vastness of space, and as we see the same flickering lights on the screen, we understand what he means. Compared to the fantastic technology it took to get him there, the campfires seem to be part of another world.

The views of Earth as a tiny globe of blue and white and tan, floating alone in black space, are still amazing after all these years. "You don't think of it as Texas or the United States," says one of the Moon travelers; "you really think of it as Earth." Sometimes it's hard to remember that the film uses no special effects. When the completed movie was screened for a group of astronauts at the Air and Space Museum in Washington, Apollo 11 veteran Buzz Aldrin said it was "the closest thing to going."

Spectacular footage requires the right music, and avant garde composer Brian Eno has provided a beautifully understated score that avoids the pomposity often heard in space documentaries. Reinert also includes selections from the tapes some of the astronauts brought along with them—songs running the gamut from Buck Owens' *Act Naturally* to Berlioz' *Symphonie Fantastique.*

For All Mankind won the Grand Jury and Audience Awards at the U.S. Film Festival, but distributors spurned it, saying that documentaries don't make money. Although it eventually will be out on home video, Reinert says that for full impact it has to be seen on the big screen. After limited showings in four cities last year (it was the third largest grossing film per screen in the United States in November), Reinert and a partner are distributing the film themselves; it's set to open nationwide in March.

Some people question whether the cost of the Apollo missions was justified. Those who see *For All Mankind* are apt to say we got our money's worth. □

The first TV show from the Moon: still amazing after all these years.

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MISSION FILE

STS-33

LAUNCH: 7:23 p.m. EST, November 22, 1989 Pad 39B, Kennedy Space Center, Fla.
LANDING: 4:31 p.m. PST, November 27, 1989 Edwards Air Force Base, Calif.
ORBITER: Discovery
ALTITUDE: Classified; estimated 110-280 nautical miles
CREW: Frederick D. Gregory, Commander
John E. Blaha,
Pilot
F. Story Musgrave, Kathryn C. Thornton, Manley L. "Sonny" Carter, Mission Specialists
PAYLOADS: Classified; believed to be signals intelligence (SIGINT) satellite, SDI experiments, medical investigations

Even though you won't find the full story of STS-33 in the public record, this secret shuttle mission was one for the space trivia books. Discovery's five-day flight not only turned out to be the last shuttle mission of the '80s, but it also featured a host of "firsts": the first post-Challenger night launch...first black shuttle commander...first civilians to fly a military mission...and, of course, the first soccer ball in orbit.

NASA had announced in advance that STS-33 was slated to make a rare night liftoff sometime within a pre-selected four-hour launch window. In keeping with policy on classified flights, however, the space agency gave no reason for launching in darkness. Liftoff times normally are dictated by the need to place the primary payload in a particular orbit.

As usual with these secret flights, NASA withheld the exact liftoff time until T-9 minutes (even though a display at the agency's headquarters in Washington had been showing the correct time-to-launch for two days). When the countdown neared zero, the darkness at Pad 39B exploded in a fireball of brilliant white light as the shuttle's three main engines and solid boosters ignited to send Discovery hurtling through the warm Florida air.

It was an extraordinary evening for shuttle watching. Spectators at Cape Canaveral clearly saw the solid rockets separate nearly 30 miles over the Atlantic, and the bright pinpoints of light from the orbiter's main engines were visible in long-range tracking cameras almost to the moment of cutoff.

Once Discovery was safely whirling around the globe, the astronauts prepared to release their hush-hush cargo. Most analysts agreed with the assessment—first published in the trade journal *Aviation Week & Space Technology* , that the orbiter carried a 6,000-pound signals intelligence satellite to allow the National Security Agency to tune in to Soviet military communications. Whatever it was, the payload was successfully deployed early on Thanksgiving Day, according to reports from amateur satellite trackers. Presumably the craft was lofted into a high geosynchronous orbit by an Inertial Upper Stage booster.

NASA maintained its customary silence about the secondary objectives of the mission as well, but the assignment of two physicians—Story Musgrave and Sonny Carter—to the crew strongly hinted that a full slate of medical experiments was planned. There also were pre-launch reports that the astronauts were given tasks related to SDI research and the role of humans as space-based military observers.

The presence of civilians Musgrave and Kathryn Thornton onboard a classified shuttle flight was a first. On all four previous Department of Defense missions, the crews were composed entirely of red-white-and-blue military men; two of the flights had even included career Air Force officers as payload specialists in place of NASA astronauts.

The pilot for STS-33, John Blaha, had not expected to be

Discovery's liftoff, as seen from a training aircraft.

Following their perfect landing, Thornton, Gregory, Blaha, Musgrave and Carter (below) celebrate with NASA officials.

floating about Discovery's cabin again so soon. After his successful debut as the orbiter's pilot on STS-29 in March 1989, Blaha might have been in line to command his own mission in a year or two. But when Dave Griggs, the original STS-33 pilot, was killed flying a World War II trainer in June, NASA called on Blaha as a substitute. Griggs still made the trip in spirit. He was commemorated by the solitary gold star beneath the eagle's beak on the STS-33 crew insignia.

Given the lack of official comment on the astronauts' activities, the non-technical aspects of Discovery's flight received most of the attention. Six years after Guy Bluford became the first black American to fly in space, the media took only brief notice of Fred Gregory, the first black to command a shuttle mission. Mission specialist Sonny Carter, meanwhile, got plenty of ink for the delightfully oddball and touching assortment of personal effects he carried into space: baseball cards of Dodger major leaguers Roy Campanella and Ralph Branca (Carter is a diehard L.A. fan); a sash belonging to the first mentally handicapped person to reach the rank of Eagle Scout; a soccer ball, the first ever orbited, as a tribute to the U.S. World Cup team (another soccer ball was onboard Challenger for the ill-fated STS-51L launch); and a 4000-year-old Babylonian messenger tablet, about the size of a Shredded Wheat biscuit, provided by Carter's alma mater, Emory University.

Other details about the mission leaked out only after the landing. Gregory noted in an impromptu post-flight statement that Discovery's zero-g toilet had gone on the fritz shortly after the crew reached orbit, but was quickly repaired. He also had to deal with a minor foot infection during the mission.

Even as the astronauts buttoned up the orbiter and prepared for re-entry at the end of their fourth day in space, the normally docile winds at Edwards Air Force Base turned nasty. Strong gusts swirled across the dry lake bed and runway, forcing NASA to scrub that evening's landing attempt. Suddenly unburdened, Discovery's crew used the extra time in orbit to cruise and snooze.

"We were just lying at the windows watching the world go by," Gregory later admitted. "To have seen us, it would be hard to believe we were getting paid for it."

The next day, Discovery's de-orbit burn was again bumped back, this time by 90 minutes, allowing the winds to subside. At last, the astronauts fired their engines to begin the one-hour, 20-minute fall to Earth—longer than usual due to the flight's high orbital altitude. But the weather had a final say; en route, Gregory was ordered by Mission Control to land on one of Edwards' concrete runways, because crosswinds on the lakebed were still beyond acceptable limits.

Discovery gleamed jewel-like in the late afternoon sun as it streaked in from the west and banked on its final approach. Before a few scattered onlookers (the public had been barred from the usual viewing area), Gregory and Blaha brought the 100-ton craft in for a touchdown, right on the money.

The orbiter apparently came through the five-day flight in superb shape, which should mean NASA will have an easier time preparing Discovery for its most important mission yet; this spring's deployment of the long-awaited Hubble Space Telescope. □

Space Telescope

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surveying them for temperature, pressure and composition. That's what Jim Westphal calls "plain old, simple astronomy," but only with HST is it feasible. The same kind of survey will be possible for other nearby galaxies. As Albert Boggess, a NASA astronomer who is HST's current Project Scientist, says, "Now we can [observe] something that apparently evolved independently of our own galaxy. What are the similarities and what are the differences?"

Astronomers have come to regard Andromeda as a twin of our own galaxy, but that may be the result of ignorance more than anything.

"The less you know about something, why, the more it looks like something else," says Westphal. As to whether Andromeda will turn out to be a twin sister, "I'd be willing to bet scotch whiskey that it ain't," he says. "But we'll find out. The very fact that we think it's almost like our own almost surely means it isn't."

When we look out beyond the Local Group of galaxies, which includes the Milky Way and the Andromeda spiral, we find that galaxies aren't sprinkled randomly through space but are arranged in clusters, like fleets of ships in a vast, dark ocean. The closest such grouping is called the Virgo cluster. Right now, we can easily identify stars only within our immediate grouping of galaxies. But since the Space Telescope will be able to see the galaxies of the Virgo cluster as well as we now see Andromeda, it should be able to resolve stars there.

At the center of the Virgo cluster, some 48 million light years distant, is a vast sphere of stars that is one of the brightest galaxies known. It has no name, but astronomers know it as M87, from 18th-century astronomer Charles Messier's catalog of nebulae. Virtually everything about M87 is peculiar. It is comparable in size to our own galaxy, yet it contains perhaps a trillion stars, 48 times as many as the Milky Way. Some 20,000 globular clusters—more than 50 times the number in our own galaxy—float in attendance.

Something strange is happening in M87. Radio astronomers have heard its roar of energy from across 40 million light years, and photographs have revealed the source: a strange jet of highly energized gas and electrons at a temperature of a million degrees, shooting from the galaxy's center thousands of light years into the surrounding blackness.

No one can explain the jet's existence, but it seems possible that there is a tremendously massive black hole the size of the Moon at M87's center. It may be fed by highly energized gas that surrounds the galaxy and is raining down into its center.

HST will help astronomers solve the mystery. If the telescope's pictures show that M87 has an extremely compact and bright center—indicating a denser concentration of stars than normal—that could be evidence for the black hole's existence. But for something more conclusive, Johns Hopkins astronomer Holland Ford and the Faint Object Spectrograph team plan to peer into M87 and measure the motions of stars within the core. If a massive black hole really is there, its gravitational influence on these stars should be readily apparent.

While M87's energy output is stagger-

ing, there are plenty of galaxies that make it look tame by comparison. HST's look at the processes in these powerhouses might tell us why they are different from "normal" galaxies. Is it because they contain enough gas to keep their central black hole "engines" steadily fueled? Are these so-called active galaxies really many galaxies that have merged in the past?

The same techniques that may unmask a black hole within M87 could reveal them lurking in the center of many "normal" galaxies (including our own) and even in some globular clusters. It may be that, as astronomers are beginning to suspect, there is no such thing as a normal galaxy after all.

When we look out at the universe, we look back in time. In that sense, the largest telescopes are time machines. They show us the universe not as it is, but as it was. In the 1960s, the giant Palomar reflector gave us our first look at quasars, strange creatures from the early days of the universe. On photographic plates they appeared as starlike points of light, and at first astronomers were sure they were located within our own galaxy. But none of the signatures of familiar elements could be found in their spectra. It was Caltech's Maarten Schmidt who realized the reason: the spectral lines had been displaced by huge redshifts, meaning that the quasars were extremely far away, and were moving away from us at enormous speeds. To be visible across such vast distance they also had to be putting out awesome amounts of energy—100 times the output of the entire Milky Way galaxy—from a region no bigger than a single star. Compared to a quasar, even a galaxy like M87 is a quiet place.

"There's going to be jillions of stars we haven't seen before."

Quasars are so distant that astronomers cannot know exactly *how* distant they are without first resolving the uncertainties in the rate of expansion of the universe. According to estimates, the light we receive from the most remote quasars may have begun its journey as long as 15 billion years ago, perhaps only a couple of billion years after the Big Bang. In these brilliant beacons we see the universe in near-infancy. Astronomers suspect that quasars may be the bright cores of ancient galaxies, but until HST gets a look, most of them remain specks of fuzz on photographs. "I'm pretty sure that we will see galaxies [around] all of them," says Duccio Macchetto, whose Faint Object Camera will provide the most detailed images.

By revealing what quasars look like in detail, HST should answer astronomers' most basic question about them: Are they a strange, extinct species with no link to modern-day galaxies? Or do they represent an early evolutionary stage—perhaps, as Albert Boggess suggests, the "terrible two's" of a galaxy's life?

How galaxies came into being is a matter of great debate among astronomers. Macchetto favors the view that they formed from small bodies that coalesced to become progressively larger objects. If he's right, the HST images could show ancient

galaxies every bit as strange in their way as pre-Cambrian fossils—galaxies with two, three or even four nuclei, afloat in a spray of newly formed stars. There could be galaxies in the process of merging with one another and other strange forms that existed only in some ancient time, before they assumed more familiar shapes. Ultimately we may learn that quasars and other types of extremely luminous galaxies are the ancestors of our own.

In 1939, when the 82-inch telescope at the McDonald Observatory in Texas was dedicated, Otto Struve, one of the greatest astrophysicists of his day, predicted what it would do. He was wrong on every count. Since then the science of astronomy has been transformed again and again by new finds raising new questions. Consider the discoveries of the last two decades. Astronomers have learned of the probable existence of black holes, stars so massive that not even light can escape from them. There are objects in deep space that act as gravitational lenses, distorting the images of quasars beyond. On the largest scales we can observe, galaxies congregate in superclusters arranged around vast empty spaces like cosmic soap bubbles. Ninety percent of the mass in the universe may be taken up by matter we cannot see. Each of these revelations came while the Space Telescope was taking shape. No wonder that everyone connected with the project says that, as with every other major telescope, its most important discoveries are the ones we can't predict.

Despite the general expectation that HST will discover whole new classes of objects, astronomers won't be able to sweep the heavens at random, looking for something completely unexpected. Aside from the demands on the telescope's time, none of the instruments observes enough sky to make that practical. The Wide Field/Planetary Camera has the widest field of view on the telescope, but "wide" in this case is an overstatement. If you hold a dime at arm's length, the middle of the o in "one" is the same size as the patch of sky photographed by the WFPC in its "wide field" mode. In astronomical parlance, that's a little under 3 minutes of arc, a tiny fraction of the area covered by a single photographic plate from a ground-based

sky survey. Nevertheless, Westphal's group plans to use the WFPC for a "mini-survey," just to see what's out there. They'll aim HST at the emptiest patches of sky they can find, and take exposures just over 38 minutes long—the longest possible in one orbit. Westphal says there's no point in guessing what the pictures will show, but he's certain they will be among the most sought-after of HST's images. "Everybody's going to be grabbing a copy of the data, and playing with it their own way on their own terminal." Westphal's team of astronomers will be like kids on Christmas morning.

On his desk at the Institute for Advanced Studies, John Bahcall has a piece of paper bearing a quote from the Old Testament: "If you want to tell lies, you should tell them about things that are far away." Perhaps HST's main mission is to find out whether we've been telling ourselves lies about the way the universe works. Big Bang cosmology says that the universe is expanding like raisin bread rising in the oven. Wherever you are, the farther away you look, the faster the raisins recede from you, carried by the expanding dough. The sight of galaxies rushing away from us at ever faster rates the farther we look appears to confirm this. But despite tremendous effort, astronomers cannot measure the rate of that expansion accurately, because it's so difficult to determine distances, even to the nearest stars. What astronomers call the cosmic distance ladder is a rickety one; each rung is an assumption. As a result, current estimates of the rate of expansion of the universe vary by 100 percent. Nor are we certain of another crucial piece of information, the rate at which this expansion is slowing down.

The key to the cosmic distance ladder is a type of star called a Cepheid variable, whose true brightness can be found by measuring the length of one cycle of variation of its apparent brightness. Once we know how bright it really is, we know how far away it is.

Earthbound telescopes can spot Cepheids only in the nearest galaxies, but they are far from ideal measuring posts; the closeness of these galaxies means that they are receding from us relatively slowly. It is difficult to distinguish their recessional velocities from their own random motions.

But if HST performs as well as expected, it should be able to spot Cepheids in the Virgo cluster of galaxies 40 million light years distant, where recessional velocities far outweigh random motions. That will help astronomers slowly chip away at the uncertainties in the expansion of the universe. And that, says John Bahcall, may be the point at which we realize we've got it all wrong.

"I'll give you an example of something crazy that Space Telescope could find." Just suppose, he says, that HST's results say the expansion rate is different depending on which direction you look. That would throw our accepted notions of cosmology in doubt.

But Bahcall says that's only too possible. "I'm uncomfortable with the idea that the entire fate of the universe from its inception to its ultimate evolution is determined by a single set of finite equations, that there are no unknowables, and that's

all there is to it."

The Space Telescope's greatest impact may be to add the Big Bang to a long line of mistaken cosmologies, from that of the ancient Hindus, who believed that the Earth rested on the backs of four elephants who stood on a giant tortoise swimming in a river of milk, through Ptolemy's Earth-centered universe. It was, after all, a telescope that toppled Ptolemy's cosmology—a telescope built by Galileo.

For all their anticipation of what the Space Telescope will tell them, the astronomers' biggest hope right now is simply that it will work. As O'Dell says, "It's only a machine, and machines can break." Right down to its last few months on Earth, the complex spacecraft was still causing headaches for its creators. Last fall technicians discovered soldering flaws in the guts of the Wide Field/Planetary Camera. Had they gone undetected before launch, it would have been only a matter of time before the WFPC stopped working.

"That was pretty scary," Westphal says. "We'd run 8,000 hours of operating time with never a glitch, and then all of a sudden these bad solder joints showed up. It was a low-technology problem. After 8,000 hours who's going to worry about bad solder joints anymore?"

HST was designed to be brought back to Earth for repairs if necessary, but tight schedules for the space shuttle mean that option may not always be available when needed. Most astronomers are resigned to the idea that the telescope won't function perfectly. Holland Ford says, "I think it's a safe prediction that everything's not going to work. The big question is, how much of it *will* work?"

"You always worry," Westphal says. "I worry about that now. We'll all go down to the Cape and watch this thing launch, and there'll be 20 minutes when all of us will have our heart in our hands."

After that ordeal of fire and noise is finished, and after the months of testing are over, the astronomers will come to the moment some have given 20 years of their lives to make a reality. "I think I'm going to have so much fun it'll be like being let alone in a toy store at night with nobody else around," Bahcall says. "I don't dream about anything in particular; I just dream about having good data. If the instrument operates properly, then we'll all have a fabulous time." ☐

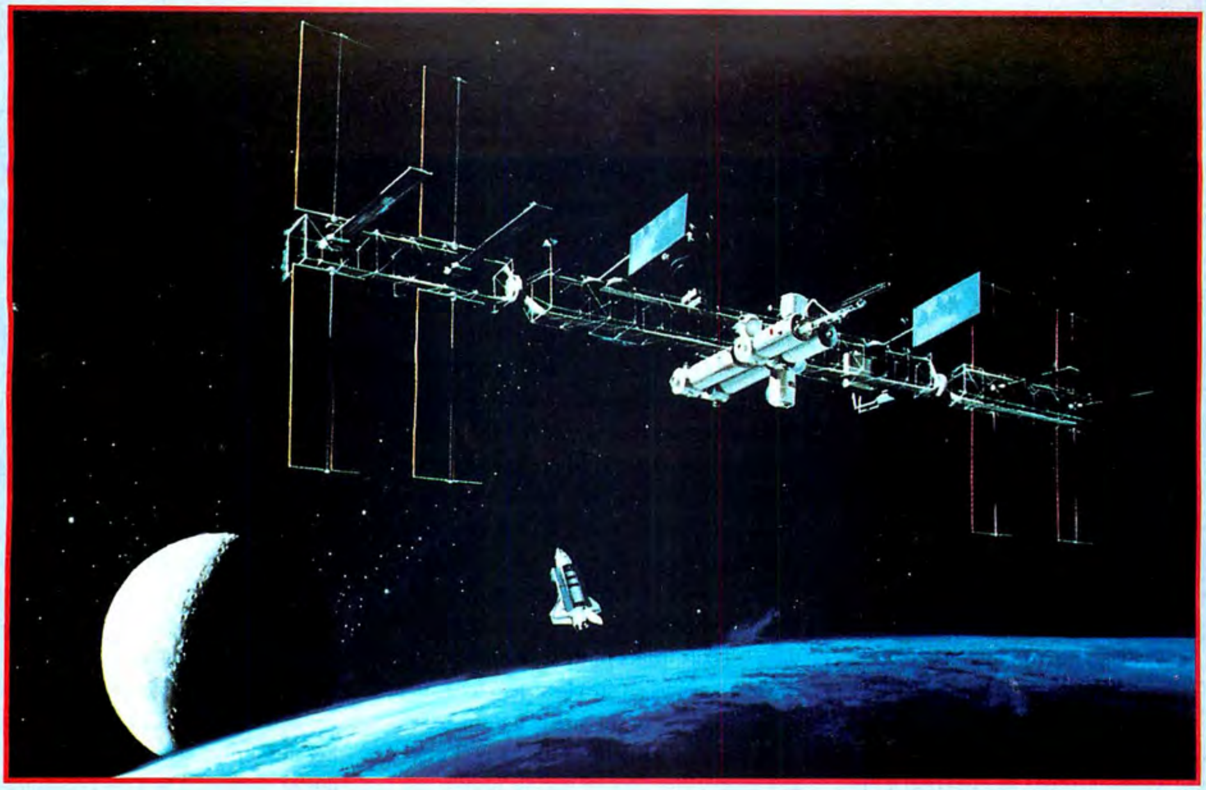
Machine

continued from page 26

of an arc second for up to 24 hours. That job will be done by the Fine Guidance Sensors, which, according to former HST Project Scientist C. Robert O'Dell, are "wonderfully, horribly complex, and at the same time simple devices." They are the most complex part of the entire spacecraft.

While the technology for HST is on a par with that used in military reconnaissance satellites, the similarity is only superficial. No spy satellite faces the same stringent pointing requirements. And HST's need to observe extremely faint objects— millions of times dimmer than the dimmest stars visible to the naked eye—meant that astronomers had to develop entirely new instruments, many of which required advances in the state of the art.

The Space Telescope's instruments are similar in design to what you'd find in a mountaintop observatory, and that is no coincidence: Much of the technology for today's detectors was developed for HST. A case in point is the workhorse of the telescope's instruments, the Wide-Field/Planetary Camera (WFPC), which makes use of an electronic sensor called a charge-coupled device (CCD). In the late 1970s, when HST's design was finalized, CCD's were a relatively untried technology, and O'Dell remembers taking a deep breath when the decision was made to use them. Since then, CCD's have been in use in observatories across the United States, largely because prototypes built for the Space Telescope were made available to astronomers. Electronic sensors have all but replaced conventional film cameras in professional observatories, and for good reason. Photographic film has a "quantum efficiency"—that is, the fraction of incoming photons that are recorded—of around 2 or 3 percent. CCD's deliver a whopping 80 percent, and unlike film they do not lose efficiency over very long exposures. Switching from film to one of these electronic cameras is the equivalent of increasing a telescope's area 40 times.



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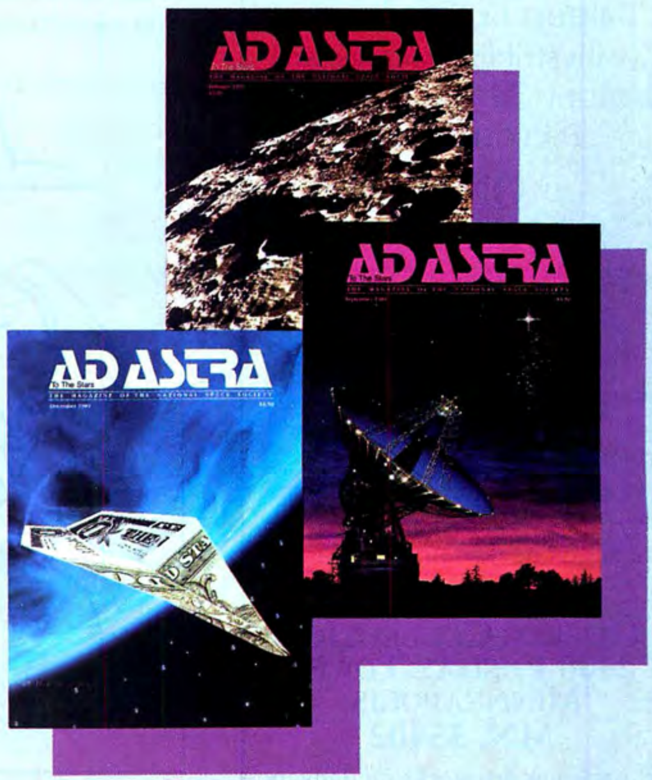

NASA astronomer Albert Boggess, who took over as HST Project Scientist in 1985, says that while this spinoff has benefited astronomers, "it also means that in a sense we've created our own competition on the ground, and they're now ahead of us!" But whatever the edge ground-based astronomers have gained, they cannot match HST's detail or its ability to see into the ultraviolet. To astronomers interested in the processes that power stars and active galaxies, ultraviolet is where the action is.

If the WFPC is HST's workhorse, then the Faint Object Camera (FOC), the European Space Agency's main contribution to the telescope, is its virtuoso performer. It will see the faintest objects and the finest details. In its highest resolution mode it surveys an area less than four arc seconds square, or the size of a dime seen from three quarters of a mile away; Pluto and its satellite Charon will fit neatly within the frame.

But in astronomy, pictures only tell part of the story. The spectrum of a star or galaxy is what reveals its composition, temperature and the physical processes going on inside it. HST carries two spectrographs, one for faint objects and another that sacrifices sensitivity for the ability to split starlight from brighter objects extremely finely.

Last, but not least, is the High Speed Photometer. Atmospheric turbulence hampers astronomers' efforts to measure extremely rapid changes in a star's or galaxy's light. But this instrument, which has no moving parts, will be able to record changes occurring in a span of microseconds. To make the most of the Space Telescope's time, the instruments are mounted so that more than one can operate simultaneously. The Faint Object Spectrograph, for example, can gather spectral data on stars in the core of a galaxy while the WFPC records images of the galaxy's halo of globular clusters.

The combination of the pointing system's accuracy and the sensitivity of the instruments is what gives Space Telescope its extraordinary power. The telescope's pointing system is so precise that it can interrupt a long exposure of a distant target and come back to it later, without being so much as a single picture element out of register. The Fine Guidance Sensors also will act as scientific instruments when astronomers use them to measure star positions with unprecedented accuracy.

The Space Telescope is designed to operate for 15 years, but the hope is that the observatory will last decades. Each of its instruments is designed for easy removal by space shuttle astronauts, and astronomers already are developing the more advanced instruments that will take their place.

–Andrew Chaikin

I don't know where...just OUT!

Lunar Observatory

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our own Solar System, but in theory it could see features on Pluto as small as an office building. The surface structure of asteroids and cometary nuclei would be easily within its grasp, with resolutions down to a few feet.

If we flip the switch today, according to recent NASA thinking, astronauts *could* be placing the first telescopes on the Moon sometime between 2001 and 2004. This presumes a small, four-person lunar base and a fully automated telescope package. The big telescopes would come later, as the base grows—perhaps 20 or 25 years from now.

But does lunar astronomy have to wait until the humans arrive? Not necessarily.

Stripped down to its essentials, a lunar observatory could consist of an automated telescope (built and packaged to be as lightweight as possible) plus a suitable power supply, a lander and a launch vehicle to get it all to the Moon.

"My own view," says Michael Mumma of NASA's Goddard Spaceflight Center, who chaired a recent conference on lunar observatories, "is that one would start doing astronomy on the Moon by soft-landing robotic, small observatories. I don't think you need to have a human there to put them in place."

How big a telescope could we land on the Moon using only robotics? The Soviet Lunokhod 2, which weighed nearly a ton, went motoring around the lunar landscape collecting rocks for four months without a single hitch. And that was nearly 17 years ago.

The real advances in lunar astronomy, however, will come when settlers and construction crews are living there permanently. At some stage between the first spartan Moonbase and a spreading underground hamlet—complete with monorail taxis and secessionist politics—an array of lunar telescopes will dot the landscape.

And that prospect clearly pleases a veteran telescope observer like Harlan Smith. "It is the long-range future of astronomy," he says. "The Moon is where you want to be." □

Robert Powers' most recent book is Mars: Our Future on the Red Planet, *published by Houghton Mifflin.*

Don't Change

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So in the end, the lasting effect of "Scrub '89" was more a rescheduling than a reduction of the project. "Truly should be complimented for doing a reality check," said one influential congressional staffer. "NASA was never going to get what it requested."

If anything, the situation will be worse this year. As a new round of budget hearings gets underway this spring, few on Capitol Hill believe the space station will get the full $2.7 billion its managers say they need, particularly with other projects like the new Earth Observing System competing for start-up money. Once again, NASA managers will have to defend—and maybe amend—their plans for Freedom.

As for Kohrs, he plans to stay with Freedom for a "long time. I'm dedicated to that." But this mild-mannered career man, who has spent most of his professional life on the Apollo and shuttle programs, won't say with equal conviction that the Langley episode is completely behind him.

"I can't tell you what the circumstances will be next year," he said, sitting in his office, with its spectacular view of Capitol Hill. "You may have a major technical problem next year." Or, of course, another budget setback. That, after all, has become a familiar part of the landscape. □

Lori Keesey is a freelance writer and former editor at Space Commerce Bulletin.

Great Observatories

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with a $1.2 billion price tag. If plans go as scheduled, AXAF will be launched from the shuttle in mid- to late 1996. The last U.S. x-ray satellite, the Einstein Observatory, ceased working in 1981. AXAF will detect high-energy radiation involved in such processes as the birth and death of stars, black holes, hot intergalactic gas and the diffuse cosmic background.

The last of the Great Observatories to reach orbit will be the Space Infrared Telescope Facility. Although feasibility studies have been done and research teams chosen, SIRTF has not yet been proposed as a "new start" in NASA's budget. If funded, the instrument will be slated for launch sometime in late 1998 or early 1999.

SIRTF, expected to cost $800 million, is designed to look at some of the coolest objects in space. Astronomers hope its three onboard instruments will reveal information about star formation and the existence of other solar systems over the course of its five-year lifetime. SIRTF will follow up on the work of the Infrared Astronomical Satellite (IRAS), which conducted the first infrared all-sky survey and found some 300,000 objects before it ended operations in 1983. The instrument should also be able to shed light on the earliest stages of galaxy formation and on quasars, which are among the most powerful sources of radiation in the universe. —*Karen Hartley*

I SAID I can't see a thing!

Onboard Freedom

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can be swapped for a new one when necessary. Because of the deck and attic, the interior of the main module will be about ten feet smaller than the U.S. or European modules — not surprising, considering the Japanese skill in getting maximum use from limited space.

Like Japan, Europe has no intention of being left behind in the space station era. Despite overwhelming political and logistical problems, the European Space Agency (ESA) has anticipated the approaching unification of western Europe with an ambitious space agenda of its own. On flight twenty, Europe's major contribution to the station will arrive — Columbus, Freedom's last major component.

Columbus will be roughly the same size and shape as the U.S. modules, and is based on the Spacelab attached laboratory that now flies in the shuttle cargo bay. ESA will staff the module with two crew members, and will use it as a foundation for either expanding European presence on Freedom or building a separate station of its own in the future.

Over the next seven months, nine more shuttles will haul up the supplies necessary to operate the station — racks of experiments, spare parts, food, oxygen and, of course, Freedom's first full international crew — eight people who will be among the first of a growing group lucky enough to live and work on the most remote of all outposts.

A thousand years ago, the construction of great cathedrals marked the end of the millennium — a way of preparing for the Day of Judgment that many thought was soon to come. Freedom is, perhaps, a kind of new age cathedral.

Certainly it is a monument, if not to Armageddon, then to an ancient desire that still draws us, very literally, heavenward. If schedules hold, the space station's first crew will pass the final summer of this millennium gazing down upon the world of their origin, and perhaps will see it in a new light. In some small sense, it will no longer be our only home. □

Chip Walter is a Los Angeles area writer and film maker who would give anything to live and work on the space station.

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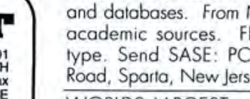

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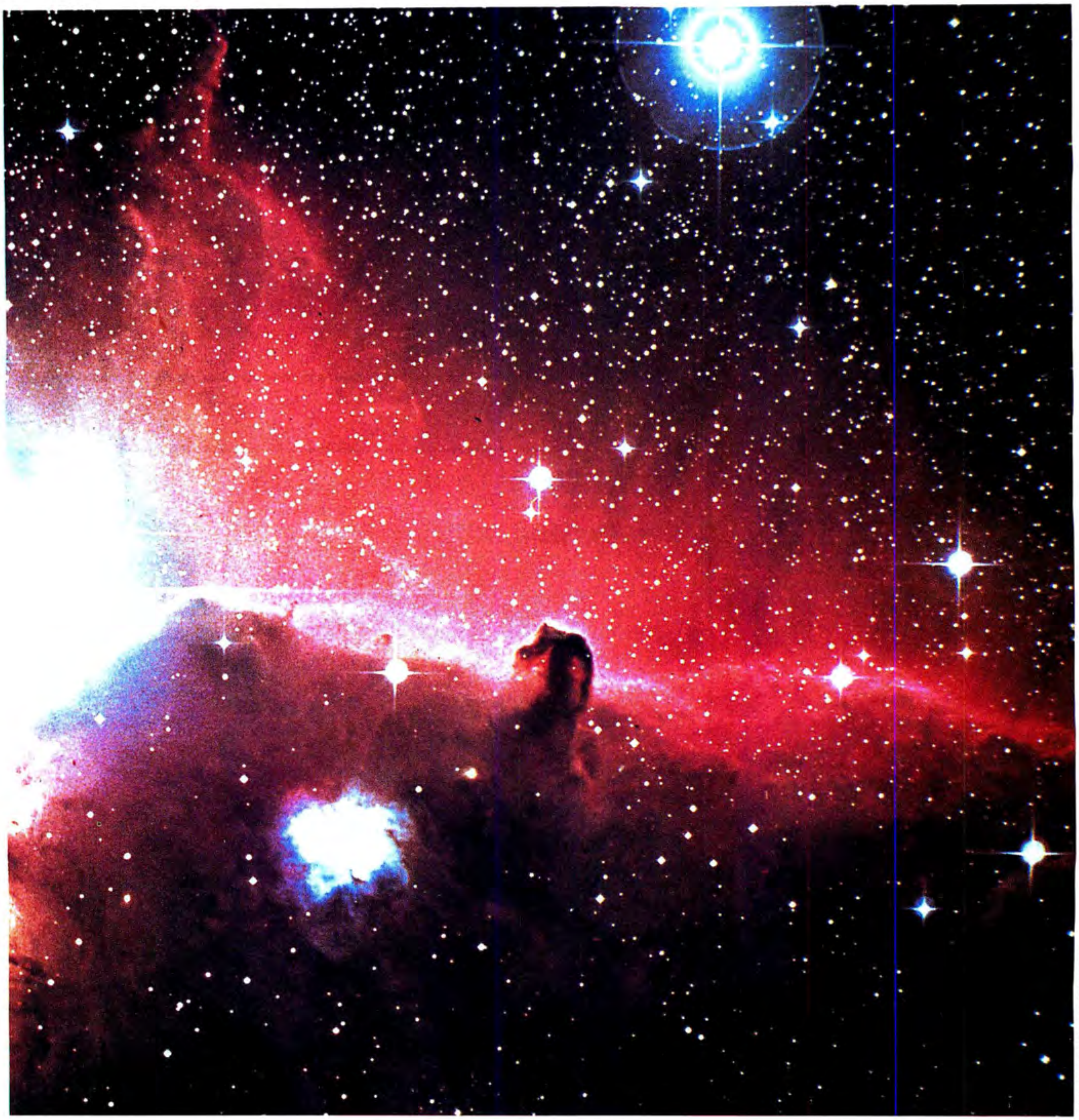

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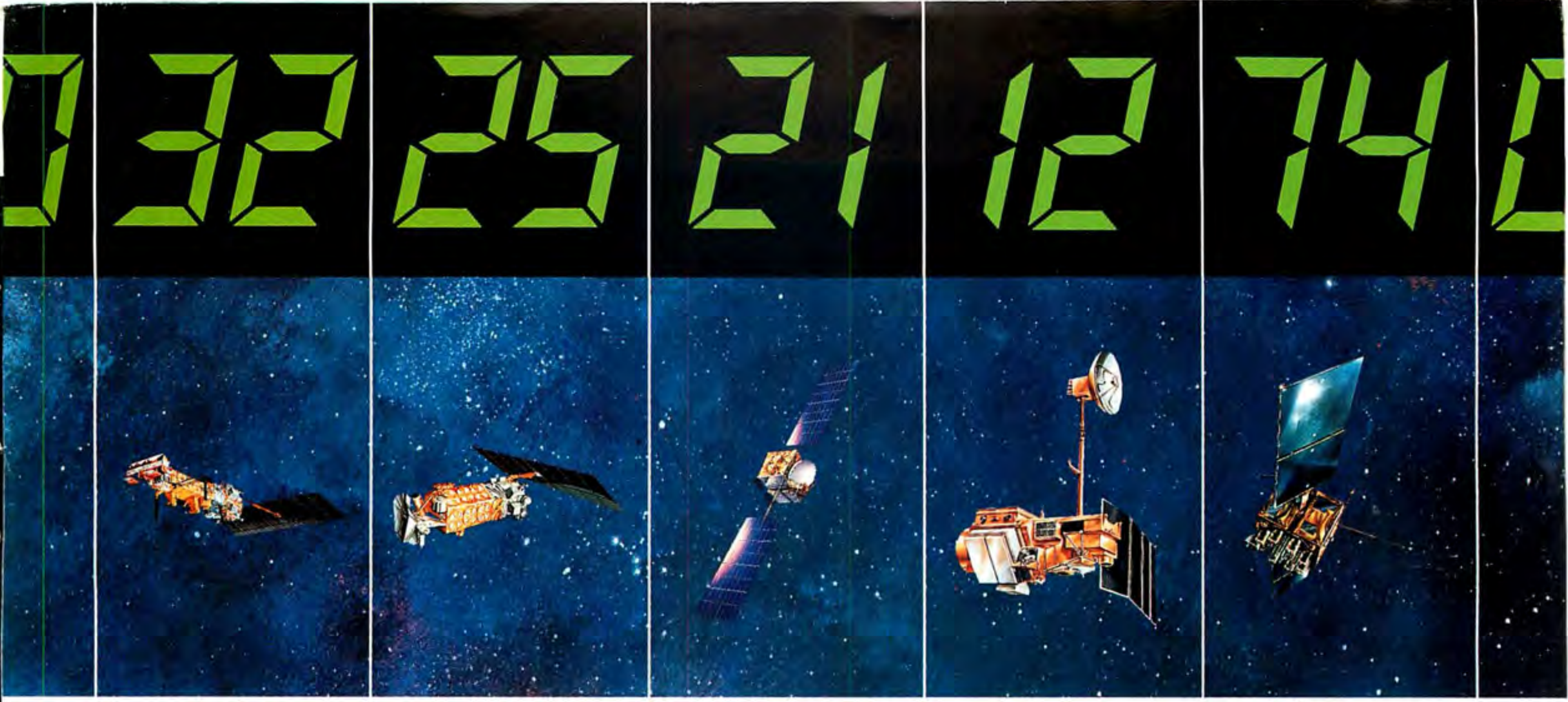
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